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Effects of Blackout on British Columbia Sp[illegible] Seedlots at Red Rock Research Station

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ABSTRACT

Four dynamic photoperiod (short-day) treatments, each declining in parallel with the natural ephemeris (nominal 19-, 17-, 15-, and 13-h days), were applied for three durations (2, 4, or 6 weeks) to six seedlots from three spruce species (*Picea glauca*, *P. engelmannii*, and *P. sitchensis* x *P. glauca*) at Red Rock Research Station, near Prince George, British Columbia. Short-day dynamic photoperiod treatments effectively controlled seedling height without inducing major root dry matter loss, and upon planting, all stock had minimal phenological disruption and there was no carry-over effect on first-year farm-field height increments. The dynamic short-day treatments also positively affected first-year root collar diameter increments. No one blackout regime was best for all species and seedlots, suggesting that unique blackout strategies are required for species and seedlots with different levels of physiological vigour.

The dynamic blackout treatment appeared to induce less phenological perturbations in the Sitka-white spruce hybrid than previously indicated for conventionally applied static (e.g., constant 10-h day and 14-h night for four weeks) blackout treatments. This indicates the need for direct comparisons between static and dynamic applications of blackout, both at the nursery and in the field.

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1 INTRODUCTION

Controlling the height of spruce seedlots (*Picea* spp.) to desired standards is a recognized problem at high latitude nurseries in British Columbia. Nutrient- and, more commonly, drought-stressing techniques are often used to control seedling height (D'Aoust and Cameron 1981; Matthews 1981; Johnson 1985). Drought stressing, however, can be biologically hard on seedlings, resulting in poorer quality and slower bud formation (MacDonald and Owens 1988) and in reduced root mass (Johnson 1985; Arnott *et al.* 1988). Height control through nutrient stressing is not well understood in conifers, nor are the biological assets and liabilities of the process. For these reasons, other means of height control should be considered, especially for northern nurseries where achieving target root mass is a perennial problem.

Photoperiodic induction of budset, or "blackout," may be an alternative to drought stressing for achieving height control in rapidly growing conifer species (Arnott and Mitchell 1981; Arnott 1982; Arnott *et al.* 1988; O'Reilly *et al.* 1989). This technique involves artificially shortening the natural day length prior to budset, thus simulating a later time in the growing season. In response, the seedling initiates budset via the phytochrome system and related processes. Cessation of height growth and apical budset and the initiation of frost hardiness and dormancy induction processes usually result from the blackout treatment (Magnesen 1969; Colombo *et al.* 1981; Dormling 1989).

Blackout is not as widely used in forest seedling nurseries as in floricultural and horticultural nurseries because its utility has not been fully demonstrated. That is changing in British Columbia as the number of blackout-treated seedlings are currently increasing as are the demands for applied blackout research.

Blackout treatment of conifer seedlings is not without its problems (cf. Dormling 1989). Generally, blackout-treated stock is smaller because the shortened photoperiod reduces carbon production (Nelson 1963), although this may be offset by a reallocation of carbon to the roots rather than to the shoot (Zelawski 1957; Hawkins and Hooge 1988). The largest potential liability for blackout-produced stock is its altered phenology after treatment (Hawkins and Hooge 1988; Odlum and Colombo 1988; Silim *et al.* 1989). Seedlings exposed to long nights for 4–7 weeks produce buds that flush readily after exposure to favourable growing conditions (Dormling 1989). Overall, stock may flush earlier in the spring and grow later into the fall than would stock not undergoing blackout. This can predispose the stock to injury or damage induced by spring and fall low temperatures.

The usual operational blackout treatment in southern British Columbia nurseries is to place seedlings in an unchanging treatment of approximately 8-h day/16-h night environment on or about July 1 for up to 4 weeks (Matthews 1983; MacDonald and Owens 1988). This ensures that critical day length is not exceeded. If this protocol were used at high latitude nurseries, a significant proportion of the photosynthetic production possible under the long northern days would not be attained. Another consideration at higher latitudes is the large difference between blackout treatment and ambient day lengths. The photoperiod can be increased by up to 8 h once stock is removed from an 8-h photoperiodic induction treatment in late July. The potential would then exist for "reflushing" to occur in seedlots with vigorous growth, once stock is returned to ambient photoperiod. Since buds formed during short nights are not initially stable (Dormling 1989), it would therefore be desirable at high latitude nurseries to have the longest possible photoperiod that results in budset without reflushing, so the impacts on carbon production and allocation can be minimized.

As conifer needles exist for many growing seasons, their phytochrome system likely responds to many more environmental inputs than just absolute day length (Saunders 1982). Olson *et al.* (1959), for example, suggested that plant growth is the net response to all environmental factors. Nevertheless, the southern British Columbia blackout regime is based on the assumption that absolute or critical day length is the sole environmental input. This is not supported by Olson *et al.* (1959) who found that changes to day length either above or below the critical value can influence growth and dormancy, so there is no absolute threshold. At the same time, critical day length can change for a species along a latitudinal gradient (Pollard *et al.* 1975). Northern provenances ceased growth under longer photoperiods than did southern provenances. The critical day length in *Acronycta rumicis* increases by about 1.5 h with every 5° increase in latitude; for example, 43, 50, 55 and 60°N latitude, respectively, have critical day lengths of 14.5, 16.5, 18 and 19.5 h (Danilevskii 1965).

It is unlikely that the photoperiodic response is controlled by a single mechanism (Vince-Prue 1976). The phytochrome system may respond, in addition to the absolute photoperiod, to the increasing or decreasing rate of change of day length in conjunction with the absolute day length (Saunders 1982). It may also respond to other environmental cues such as thermal inputs, which enable the physiological systems of the seedling to distinguish between spring and fall (Saunders 1982).

Clearly then, a blackout protocol should not simply consider critical day length, but should take into account the many factors that can affect the phytochrome system and budset. Such a treatment would decrease photoperiod parallel to the natural ephemeris for a given nursery latitude resulting in *dynamically* increasing night lengths, rather than the conventional *static* night length, over the treatment period (Figure 1). Thus, while offset in terms of actual hours, the treatment ratio of day to night length over time is that of the ambient ephemeris. This approach would take advantage of more environmental inputs, make increased use of northern latitude long days, and, perhaps most importantly, result in no alteration in the rate of change of the day when the stock is returned to natural photoperiod from blackout treatment.

Analytically, this protocol is advantageous because it produces a constant difference between a given photoperiod treatment and ambient day length at the conclusion of any of the treatment durations, and it permits ambient ephemeris conditions to be included as a formal "control" level in treatment comparisons. Ideally, a cultural regime that results in enhanced frost hardiness and control of budset should produce seedlings better in tune with the outplanting environment (D'Aoust and Cameron 1981; Thompson 1981). Seedlings not in tune with their outplanting environments is a matter of increasing concern in British Columbia.

The experimental series described in this report includes a number of spruce seedlots and photoperiod duration combinations, because blackout affects seedlots differently as a result of genotype x environment interactions (Roche 1969), and seedling response to photoperiod, light, and temperature varies at different stages of growth (Weiser 1970; Rosvall-Åhnebrink 1981). The rationale for adopting night length treatments shorter than normally used is based on the 1987 growing season experiences at Red Rock Research Station

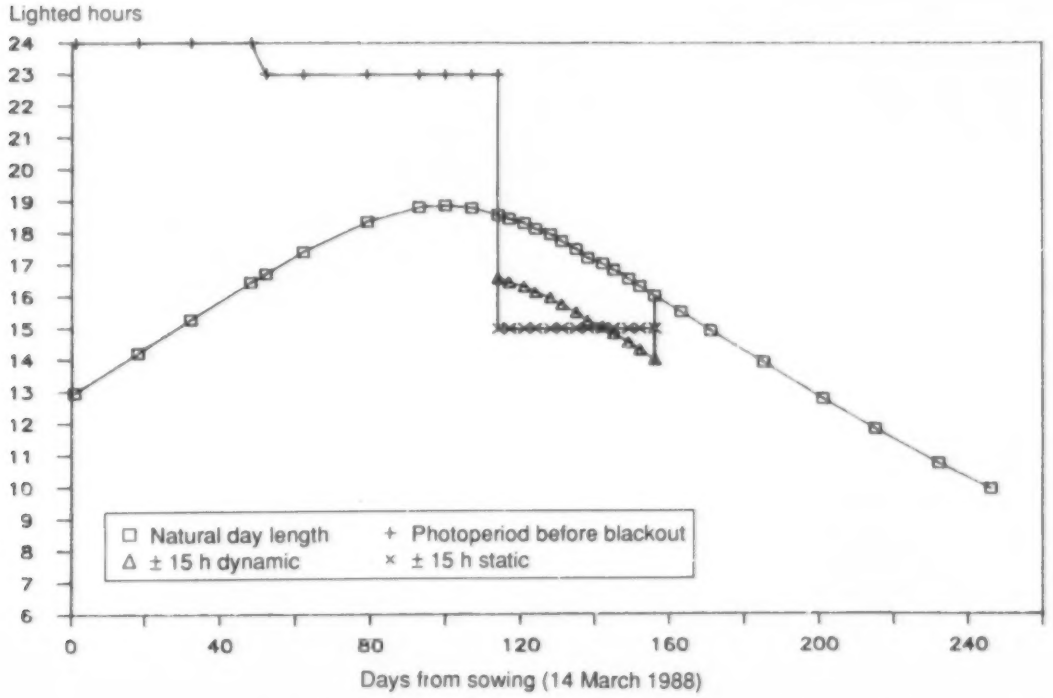

FIGURE 1. Natural ephemeris at RRRS with a dynamic and a statically applied blackout treatment shown for comparison. Photoperiod extension prior to blackout is also shown.

(RRRS) (Hawkins and Draper 1988b; Draper and Hawkins 1989), and on data from a growth chamber photoperiod trial carried out on a Sitka spruce hybrid also at RRRS in 1987 (Hawkins and Hooge 1988). These data indicated that a 12-h night was the best compromise to optimize height control, root collar diameter (RCD), root mass, frost hardiness, and altered phenology in the field.

Four night lengths, each applied for three durations, are tested on six diverse spruce seedlots in the experiments reported here.

2 MATERIALS AND METHODS

2.1 Materials

2.1.1 Greenhouses

Seedlings were germinated and grown in three 6.5 x 12 m Harnois Nordique® and one 9.1 x 18.3 m Harnois Ovaltech® double poly greenhouse at RRRS, near Prince George, B.C. (Lat. 53° 45' Long. 122° 41').[1] The smaller houses are equipped with Modine 149 400 BTU furnaces and two Acme 5700 cubic feet per minute (cfm) exhaust fans; the larger house has a 280 000 BTU furnace and two 10 200 cfm fans. All houses have 400 W high pressure sodium lamps for photoperiod extension, giving a minimum of 5 μmols m^{-2} s^{-1} at styroblock level to prevent premature budset (Arnott and Mitchell 1981). Fertilization, misting, and irrigation are supplied with Munckoff overhead travelling double booms. Fertilizer is applied in irrigation water using a Pulsa Series injector controlled via an electro-conductivity loop. Underbench heat is supplied by perforated plenums to a bench system skirted during the germination period.

An ESC Access 2000® computer system was used in the four greenhouses to control all functions related to short-day treatment — heating, venting, fertilization, misting, and irrigation. Linked programming between physically separate greenhouses ensured common environmental conditions before treatment (Section 2.3.1). A series of air and soil temperature sensors provided a daily record of individual greenhouse conditions.

The three small greenhouses are equipped with VRE blackout system Enershade 100 S/B shade cloth (100% blockage), as well as LS 11 reflective cloth (95% blockage) (Hawkins and Draper 1989). Blackout curtains were used to shorten natural (ambient) day length by equal lengths in the morning and evening.

2.1.2 Growing regime

Seed was sown on March 14, 1988, in PSB 313B poly styroblocks (160 cavities, 764 cavities · m^{-2}). The soil medium was a peat:vermiculite mixture, 2:1 (v:v), with gypsum and 12 mesh lime supplements at 1.0 and 0.9 kg · m^{-3}, respectively. Media density averaged 0.09 g · mL^{-1} after compaction into styroblocks. Seeds were covered with a thin layer of forestry sand. Media specifications were modified from Matthews (1981) and Draper and Hawkins (1989).

After sowing, a standard B.C. Forest Service (BCFS) misting regime was followed, in which frequent low volume mist applications of fertilizer-free water were made until the secondary needles became visible (Matthews 1983). Photoperiod was extended to 24 h (March 14 – May 5), and then reduced to 23 h until short-day treatments began (July 6, 1988), to prevent premature budset (Tinus and McDonald 1979).

During germination, blackout curtains were closed on cold nights to conserve fuel and maintain night temperature setpoints (Hawkins and Draper 1989). Greenhouse air temperature environments, photoperiod, and fertilizer regime (modified from Draper and Hawkins 1989) are summarized in Table 1. Forestry Seedling Special, 20-8-20 N-P-K (Plant Products Fertilizer Ltd.), was used throughout the growing season (Table 1) and supplemented with Plant Products chelated trace element mix, solubor, and copper sulphate after mid-April. Trace element mix was supplied at 2.1 ppm (Fe), 0.6 ppm (Mn), 0.12 ppm (Zn), 0.03 ppm (Cu), 0.39 ppm (B), and 0.018 ppm (Mo). Solubor and copper sulphate were added at 0.4 ppm

[1] Use of a product name does not constitute an endorsement by the B.C. Forest Service.

and 1.5 ppm, respectively. Fertilizer was applied approximately twice weekly (based on the BCFS block weight method), in irrigation water at rates specified in Table 1. Periodic foliar analysis was used to monitor and correct tissue nutrient levels.

TABLE 1. Environmental regime for all greenhouses at RRRS during the 1988 growing season

Date	Temperature °C day/night	Temperature h day/night	Photoperiod h	Fertilizer regime	N ppm
14 Mar	20/20	13/11	24	Mist	0
19 Mar	20/11	13/11	24	Mist	0
18 Apr	19/13	16/8	24	20-8-20[a]	60
05 May	19/13	16/8	23	20-8-20	60
13 May	19/13	16/8	23	20-8-20	75
27 May	19/13	18/6	23	20-8-20	85
06 Jul	19/13	17.5/6.5	19[b]	20-8-20	85
			17		
			15		
			13		
20 Jul	17/11	17/7	19	20-8-20	60
			17		
			15		
			13		
17 Aug[c]	17/09	16/8	Ambient	20-8-20	50
31 Aug	17/09	15/9	Ambient	20-8-20	50
07 Sep	15/08	15/9	Ambient	20-8-20	50
14 Sep	14/07	14/10	Ambient	20-8-20	40
21 Sep	13/07	13.5/11.5	Ambient	20-8-20	40
28 Sep	13/06	13.5/11.5	Ambient	20-8-20	40
05 Oct	12/04	13/11	Ambient	20-8-20	30
12 Oct[d]	11/03	12.5/11.5	Ambient	20-8-20	30
19 Oct	10/02	12/12	Ambient	20-8-20	30
26 Oct	09/01	11.5/13.5	Ambient	20-8-20	30

[a] Supplemented with Plant Products' chelated trace element mix, solubor and copper sulphate.
[b] Start of short-day treatments.
[c] At the end of short-day treatments, the entire experiment of 432 blocks was placed in the same greenhouse under ambient photoperiod until fall lift.
[d] Venting at 17.5°C before this date and at 15°C after.

2.1.3 Cold storage

At lifting, all stock for a given treatment combination was removed from the styroblocks. Bundles of 20 randomly selected seedlings were formed and cellophane wrapped around the root plugs. Eighteen bundles were placed in a heavily waxed paper bag. The bag was sealed closed and put in a heavily waxed cardboard seedling box. Boxes were stapled shut and placed on a pallet in the cold storage unit at -5 ± 1°C. When interior box temperatures had dropped to -2°C, about 3 weeks later, the cooler temperature was set at -2 ± 1°C. This set point was maintained until conditioning began in late March 1989.

Conditioning for 4 weeks raised the temperature in the storage unit to 5 ± 1°C to facilitate thawing of the seedlings in the spring. Once the stock was thawed, the cooler temperature was set at 2 ± 1°C until the stock was planted. Stock was removed from the cold storage unit and taken directly to the planting site on the morning of the day it was planted.

2.1.4 Field environment

Seedlings from the nursery experiment were planted at RRRS on May 8, 1989, at 0.3-m intervals along rows 0.5 m apart on raised linear nursery beds.

The nursery soil (sand to sandy-loam texture) was supplemented with 112 kg · ha^{-1} of P incorporated into the beds 2 weeks before planting as 0-20-0 Aero® superphosphate. Seven weeks after planting, 21-0-0 ammonium sulphate at 10 kg · ha^{-1}, and 0-0-50 sulphate of potash at 8 kg · ha^{-1} were added at 2-week intervals until July 21, 1989. Foliar macronutrient analysis was used to monitor plant nutrient status.

Irrigation was used to avoid spring frost and to supplement growing season natural precipitation to the nursery beds.

2.2 Nursery Treatments

2.2.1 Photoperiod (P)

All short-day treatments in this study were related to the ambient ephemeris (natural day length plus civil twilight; see Hawkins and Draper 1988a) for RRRS (Figure 2). Table 2 describes the four short-day treatments in greater detail. Day length reductions were divided equally between the morning and evening. Night length increased over the treatment period because of the naturally decreasing ephemeris (Figure 2). Within a short-day photoperiod treatment (nominally 19, 17, 15 and 13 h), the offset from the ambient ephemeris was common at both the initiation and conclusion of treatment. This is referred to as a "dynamic" short-day treatment, as distinct from a fixed day:night ratio over a given duration — "static." Short-day treatments were adjusted twice-weekly (Table 2) to follow the decreasing natural ephemeris.

2.2.2 Duration (D)

Short-day treatments were applied on July 6, 1988, 114 days after sowing, for a period of 2, 4 and 6 weeks (Figure 2). The factor duration is crossed with photoperiod, creating the PxD response surface described in Table 3.

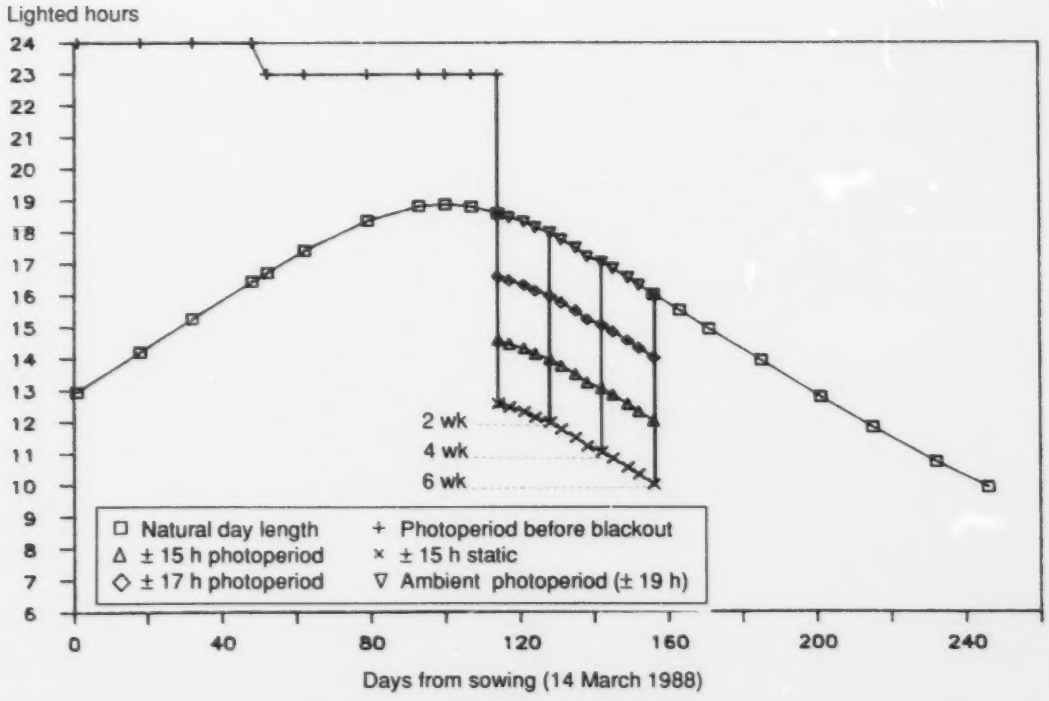

FIGURE 2. 1988 short-day treatments at RRRS in relation to the ambient ephemeris (natural day length plus civil twilight).

TABLE 2. Time clock settings for each photoperiod to provide twice weekly adjustment to the ambient ephemeris from July 6 to treatment conclusion. "On" signifies start of blackout; "off" indicates time when blackout curtains are withdrawn. All times Pacific Daylight Savings Time (PDST) (h:min).

	Photoperiods					
	17 h		15 h		13 h	
Date	On/Off	On/Off	On/Off	On/Off	On/Off	On/Off
July 06	3:57–4:57	21:32–22:32	3:57–5:57	20:32–22:32	3:57–6:57	19:32–22:32
July 13	4:06–5:06	21:25–22:25	4:06–6:06	20:25–22:25	4:06–7:06	19:25–22:25
July 20	4:15–5:15	21:13–22:13	4:15–6:15	20:13–22:13	4:15–7:15	19:13–22:13
July 27	4:31–5:31	21:01–22:01	4:31–6:31	20:01–22:01	4:31–7:31	19:01–22:01
August 03	4:44–5:44	20:47–21:47	4:44–6:44	19:47–21:47	4:44–7:44	18:47–21:47
August 10	4:58–5:58	20:31–21:31	4:48–6:58	19:31–21:31	4:58–7:58	18:31–21:31
August 17	5:13–6:13	20:14–21:14	5:13–7:13	19:14–21:14	5:13–8:13	18:14–21:14

TABLE 3. Definition of the 12 short-day treatments by photoperiod and duration at RRRS during the 1988 growing season. The nominal photoperiod at the start of the short-day treatments on July 6, 1988, are 19-, 17-, 15- and 13-h day lengths (natural day + civil twilight). The actual day length at the start, and after 6 weeks, of treatment (h:min) are: 19 h (18:35, 16:01), 17 h (16:35, 14:01), 15 h (14:35, 12:01), and 13 h (12:35, 10:01). Mean night length (MNL) is given by photoperiod and duration (h:min). Short-day accumulation (SDA) of dark hours is given for treatments at the end of the short-day treatment (h:min). Total number of dark hours (TND) accumulated is given by treatment at the end of the 6-week treatment period (i.e., night hours from short-day treatment plus night hours from 4, 2 or 0 weeks of ambient conditions).

		Duration (weeks)		
Nominal photoperiod		2	4	6
19	MNL	5:44	6:08	6:35
	SDA	80:11	171:32	276:30
	TND	276:30	276:30	276:30
17	MNL	7:44	8:08	8:35
	SDA	108:11	227:32	360:30
	TND	304:30	332:30	360:30
15	MNL	9:44	10:08	10:35
	SDA	136:11	283:32	444:30
	TND	332:30	388:30	444:30
13	MNL	11:44	12:08	12:35
	SDA	164:11	339:32	528:30
	TND	360:30	444:30	528:30

2.2.3 Seedlot (S)

Six seed sources were tested in this experiment, each fully crossed with P and D. The Forest Service's registered seedlots were selected to span an elevational and latitudinal gradient throughout the province (Table 4). Three species of spruce were included: white spruce (*Picea glauca* (Moench) Voss), Engelmann spruce (*P. engelmannii* Parry), and the naturally occurring white x Sitka spruce hybrid

(*P. glauca* x *P. sitchensis* (Bong.) Carr.) (also referred to in this paper as the hybrid, or Sxs, species). Current nursery cultural regimes do not differ greatly among spruce species in British Columbia, and control of height can be a practical problem in all.

2.3 Design and Analysis

2.3.1 Nursery

The nursery design was a completely randomized, mixed-model, three-way factorial in P, D and S, replicated 6 times. A replicate was a single poly styroblock (block) from which random individual seedling samples provide estimates of block means for analysis. Photoperiod and duration were fixed factors, and seedlots were assumed to be random (Table 5). Block mean data were analyzed from graphical plots and through analysis of variance (Proc ANOVA and Proc GLM; SAS Institute Inc. 1985). Treatment main effects and interactions were considered significant at P=0.95, and separation of means within significant effects were carried out using Duncans' Multiple Range Test (SAS Institute Inc. 1985) at P=0.95.

A single level of P was tested in only one greenhouse because of constraints on the number of blackout-equipped greenhouses available. The assumption of between-greenhouse uniformity was checked by a series of analyses on four seedling variables (total height, ground-line diameter, and root

TABLE 4. Description of experimental spruce seedlots

Seedlot number[a]	Species[b]	Map grid (N.T.G.)	Location	B.C.Forest Service seed zone	Elevation m(asl)
SL5261	Se	82 E 6	Copper Kettle	2010	1650
SL4311	Se	92 I 16	Community Lake	TOD	1435
SL8482	Se	93 A 2	Tisdale Lake	QL	1140
SL599	Sw	93 K 6	Bulkley Valley	—	760
SL8779	Sw	93 O 9	Alvin Creek	HH	1067
SL3958	Sxs	103 I 15	Lower Douglas Creek	1140	400

[a] B.C. Forest Service registered seedlot number or Interior Tree Improvement Program (ITIP) parent tree number (599).
[b] Species: Se – *Picea engelmannii* Parry; Sw – *P. glauca* (Moench) Voss; and Sxs – *P. glauca* x *P. sitchensis* (Bong) Carr., a naturally occurring hybrid.

TABLE 5. ANOVA model for the completely randomized, mixed model, three-way replicated factorial nursery experimental design. Photoperiod and duration are fixed effects, seedlots are random.

Source	df	Expected mean square	Error mean square
Photoperiod (p-1)	3	$\sigma^2e + 18\sigma^2_{PxS} + 108\phi_P$	PxS
Duration (d-1)	2	$\sigma^2e + 24\sigma^2_{PxS} + 144\phi_P$	DxS
Seedlot (s-1)	5	$\sigma^2e + 72\sigma^2_S$	Error
PxD (p-1)(d-1)	6	$\sigma^2e + 6\sigma^2_{PxDxS} + 36\phi_{PxD}$	PxDxS
PxS (p-1)(s-1)	15	$\sigma^2e + 18\sigma^2_{PxS}$	Error
DxS (d-1)(s-1)	10	$\sigma^2e + 24\sigma^2_{PxS}$	Error
PxDxS(p-1)(d-1)(s-1)	30	$\sigma^2e + 6\sigma^2_{PxDxS}$	Error
Error pds(r-1)	360	σ^2e	
Total pds(r-1)	431		

and shoot mass [O.D.]) immediately prior to blackout treatments on July 6, 1988. Tests of the null hypothesis that greenhouses were not significantly different resulted in the probability of greater F values ranging from 0.68 to 0.91. Thus, there was little indication that individual greenhouse environment had, in the first 15 weeks, affected the seedling morphological variable tested.

These same analyses were sufficiently sensitive to detect seedlot differences over the same period. Greenhouse sum of squares (n=4) ranged between 7 and 17% of seedlot sum of squares (n=6) immediately prior to blackout treatment.

To minimize bias associated with block location treatments were randomly allocated to greenhouse and greenhouse pallet positions. Possible greenhouse effects were also minimized in this way. At time of sowing, 432 experimental blocks were assigned to three jointly controlled greenhouses. Immediately prior to short-day treatment (July 6, 1988), the blocks were re-assigned random pallet positions within photoperiod groups (19, 17, 15 and 13 h) in four greenhouses. All environmental controls in the three photoperiod treatment greenhouses (17, 15 and 13 h) were linked and used to regulate the environment controls of the large house (19 h), from July 6 to August 17 (Table 1). After treatment durations of 2, 4 and 6 weeks (July 6–July 20, August 3 and 17), blocks were removed from short-day photoperiod greenhouses (17, 15 and 13 h), and randomly re-assigned to a pallet position within the ambient photoperiod greenhouse (19 h). All experimental blocks remained in this greenhouse from the end of short-day treatment until lift (November 2, 1988).

2.3.2 Field

The three-way nursery factorial experiment was field planted following over-winter cold-storage, in a completely randomized design, with three replicates of 33 seedlings in each of the 72 nursery treatment combinations (PxDxS). The analytical techniques and models used are like those discussed in Section 2.3.1, with the exception of the replication factor, which changed from six styroblocks to three field plots.

2.4 Measurements

2.4.1 Nursery

Seedling morphology was measured on random seedlings within a styroblock. Seedlings were identified within a 10 x 14 grid (excluding a 10-tree short-axis row on either block end) and selected, without replacement, from a list of random row and column values. Styroblock mean seedling height (±1 mm), ground-line diameter (RCD) (±0.1 mm), and shoot and root mass (O.D., ±1 mg) were measured eight times between July 6 (prior to short-day treatment) and October 26, 1988. Sample size was three seedlings per block (18 seedling per PxDxS treatment combination), except on October 26, when five seedlings were taken from each styroblock.

Seasonal

A continuous estimate of seedling height was given by serial measurement of a permanent sample of seedlings from April 27 to October 26, 1988. A total of 60 random trees (10 in each of six block replicates) were measured on each occasion by seedlot (prior to short-day treatment) and by PxDxS combination following treatment. These estimates guided cultural decisions and provided direct measurement of seedling height response to short-day treatments. Care was taken in the repeated measurements not to damage the measured trees. Serially measured trees were not included in morphology samples.

Not all 72 nursery treatments were necessarily represented in each morphology or serial height measurement. All treatments were measured immediately prior to short-day treatment on July 6, on August 17 (the end of short-day treatment), and at season's end (October 26).

Foliar sampling was carried out periodically through the growing season and current foliage macro- and micronutrient concentration determined (by Pacific Soil Analysis Inc., Vancouver, B.C.) to guide cultural decisions. Foliage was bulked from 16 seedling samples to estimate nutrient concentration means.

End of 1988 growing season

At the end of the nursery growing season (October 26, 1988), a five-tree sample per block replicate (n=30 trees per short-day treatment) was measured and seedling height, RCD, and root, shoot, and plant mass recorded. Seedlings were selected on the basis of random block row and column positions excluding edge row trees.

Frost hardiness testing to -18°C

Frost hardiness testing was done in a Forma Scientific biological freezer (Model 8358/8368) with a LFE Model 2010 programmable controller. Five seedlings per PxDxS treatment were randomly selected during the fall of 1988 and placed in a PSB 313B block. The three treatment durations were placed in three separate styroblocks. Two treatment duration styroblocks were randomly assigned to the first freezer run, with the remaining styroblock going in the second run (due to limited freezer capacity).

The styroblocks were put in the freezer at +3°C and held at that temperature for 1-h soak. The temperature was then lowered at the rate of $6°C \cdot h^{-1}$ (ramp) until -18°C was reached. A 1-h soak at -18°C was followed by a $12°C \cdot h^{-1}$ ramp to +3°C. After a final 1-h soak at 3°C, stock was removed from the freezer, watered well with room temperature water (±20°C) and placed in Conviron E-15 growth chambers at 30/25°C D/N air temperature, 16-h photoperiod, 400 $\mu mols \cdot m^{-2} \cdot s^{-1}$ light intensity, and 75% relative humidity. The total time for a complete freeze-thaw cycle was 8.25 h. The second run was then cycled through the freezer and held at +3°C until the following morning when well-watered and placed in the growth chamber.

Styroblocks were watered to saturation with room temperature water on days 3 and 5 in the growth chamber and then assessed on day 7. Assessments included:

- foliage browning (the percentage of the total foliage of each seedling browned by exposure to low temperature was estimated for each seedling);
- terminal bud damage (each apical bud was scored as healthy [0] or damaged [1]); and
- basal cambium damage (lower cambium was scored as healthy [0] or damaged [1]).

Means were then calculated for each PxDxS treatment. Stock was deemed ready to lift when foliage browning was less than 25% (an operational recommendation for storage from the B.C. Forest Service, Silviculture Branch) and cambium damage was less than 25% (LT_{25}) at -18°C. The percentage of bud damage was not used as a lifting criterion.

Days to bud break (DBB)

Days to bud break were determined in a growth chamber under the same conditions as for frost hardiness in the fall and winter and root growth testing in the spring (see below). There were three determinations of DBB. In fall 1988, five randomly selected seedlings per PxDxS treatment were placed in PSB 313B styroblocks which were put in the growth chamber. Four randomly selected seedlings of SL599 PxD treatments were placed in pots containing a soil mix of peat, vermiculite and dolomite lime. Each PxD treatment was replicated three times.

In the spring of 1989, five randomly selected seedlings from each PxDxS treatment were also planted in pots, with three replicate pots for each treatment.[2] Styroblocks or pots were saturated three times per week with room temperature water until tall seedlings had broken bud. They were then removed from the growth chambers.

After 7 days in the growth chamber, seedlings were assessed daily to determine if the buds had broken, indicated by bud scales opening and needles emerging. Each seedling was scored as to the number of days required to break bud and means and standard deviations were calculated for each PxD or PxDxS treatment depending on the time of the assessment.

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[2] The first 7 days were in the growth chamber, while the remainder of the period was in a greenhouse on 20°C for 16 h and 13°C for 8 h, 23 h photoperiod, and approximately 85% of ambient light levels.

Root growth capacity (RGC)

Root growth capacity was determined on the same 15 seedlings used to measure days to bud break in the spring of 1989. After 7 days in the growth chamber (under the same settings as for frost hardiness, except air temperature was changed to 25/20°C), the seedlings were carefully excavated from the pots. It was assumed that the careful handling of seedlings at this stage had no effect on subsequent measurements.

All new roots greater than 10 mm long were counted and assigned to classes according to root numbers (Burdett 1979, 1987):

Class	Number of roots	
0	None	
1	Some	< 10 mm
2	1–3	≥ 10 mm
3	4–10	≥ 10 mm
4	11–30	≥ 10 mm
5	31–100	≥ 10 mm
6	101–300	≥ 10 mm

The seedlings were then repotted and allowed to grow until bud break occurred.

The most frequently occurring class within a PxDxS treatment was taken as the class value of that group. The range of classes within a treatment group was also recorded and a treatment class arithmetic mean calculated.

Bud scale and leaf primordia estimates

Bud morphology and phenology were assessed on a single seedlot (8779) over the 1988 growing season. Five apical buds per PxD treatment were sampled at each measurement time and were fixed for bud scale and leaf primordia counts. Buds were sampled as described by Keates *et al.* (1990). The mean number of bud scales was calculated for each treatment.

The estimated number of leaf primordia were then calculated. The number of leaf primordia on the vegetative shoot were counted in three random, clockwise columns on the shoot (Pollard 1973, 1974). To facilitate the counts, the vegetative shoot was stained with diluted drafting ink (Young and Hanover 1977).

This was repeated on a sample of 15 seedlings per short-day treatment following over-winter cold-storage to allow comparison with fresh material estimates (October 1988) and needle counts following apical extension in the 1989 field season.

2.4.2 Field

Seasonal

Seedling shoot phenology was serially measured on an 18-tree sample per PxDxS treatment over the 1989 growing field season. Date and phenology index value (0 – resting spring terminal bud; 1 – swelling terminal bud; 2 – flushing [elongating] terminal bud; 3 – lateral buds forming on current shoot; 4 – terminal bud scales forming; and 5 – formation of resting terminal bud) were recorded at roughly weekly (May – June 21) and fortnightly (July – September) intervals. Modal phenology class data are presented by short-day nursery treatment over the 1989 growing season.

End of 1989 growing season

Seedling morphology (height and diameter) was measured at time of planting and after the first growing season (September 1989) on a 54-seedling sample (18 seedlings by 3 replicates) per nursery

treatment. Mean height and ground-line stem diameter (mm) were calculated and analyzed as described in Section 2.3.2. Seedling volume was calculated as one-third stem basal area (ground-line) x height, assuming a conical stem form. Height, diameter, and volume increments represent one field growing season.

Counts of needle numbers were made following the 1989 field season (September 1989). Apical extension in a nine-tree sample from SL8779 was separated into determinate (preformed) and indeterminate (free growth) sections for all short-day treatments. Free growth was identified from the formation of bud scales followed by further needle formation, or by a marked change in intercalary distance (stem unit length). Needles were counted after being removed from the preformed shoot by forceps.

3 RESULTS AND DISCUSSIONS

3.1 Nursery Seasonal Growth Data

3.1.1 Ambient (control) seedling growth

The patterns of seasonal height increment in control (ambient) photoperiod seedlings are shown in Figure 3 by seedlot, for comparison with short-day treatments. Height extension patterns were similar for all seedlots until early August, when the white and Engelmann spruce set terminal buds. The Sitka-white spruce hybrid (SL3958) continued to grow until mid-September (Figure 3). Rate of height growth in late May/early June was correlated with overall seedlot performance and final height. Only the hybrid seedlot was over Silviculture Branch height specifications at season's end. This limited height growth was typical of local growers' experience in 1988 and is ascribed to the weather in that year.

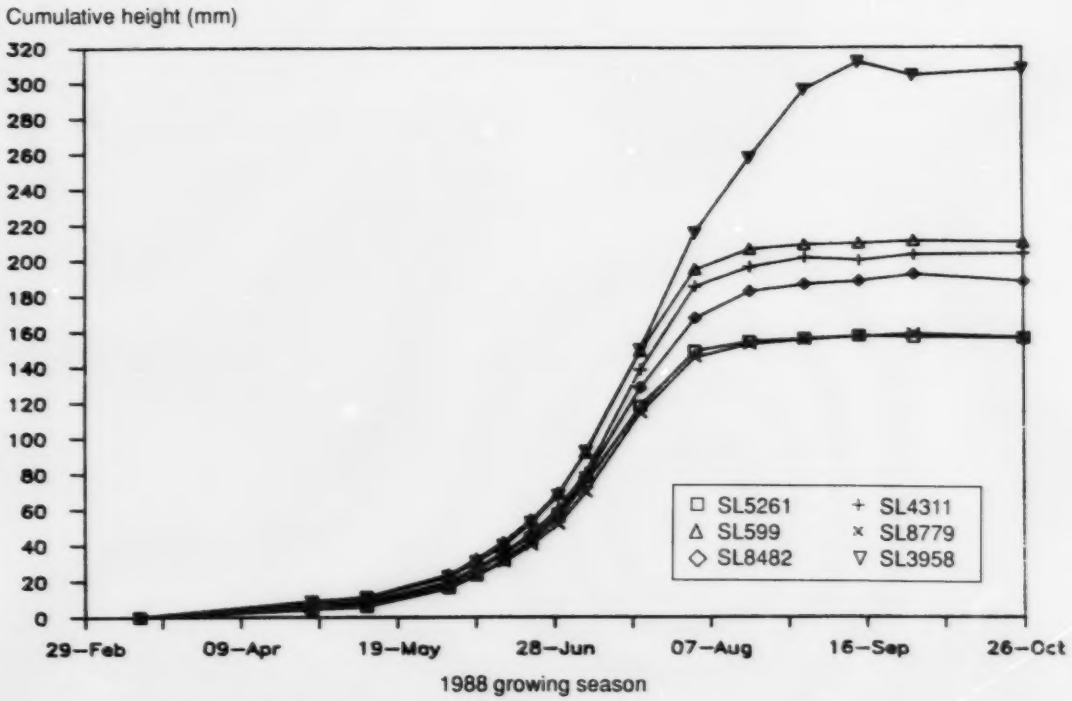

FIGURE 3. Cumulative height growth of control (ambient photoperiod) treatment seedlots in the 1988 growing season. Points graphed are the mean of 160 seedlings before July 6 and 60 seedlings after.

Seedling RCD growth over the season (Figure 4) was also similar for all seedlots. From mid-May to mid-August, RCD increased at a constant rate of about 0.6 mm/month. Following a late August/early September reduction in growth rate, all seedlots increased again in mid-late September. Diameter growth continued after height growth ceased. After late September there was little evidence of RCD growth until measurements ceased at time of lift in late October (Figure 4).

Root and shoot mass accumulation over the season are given in Figures 5 and 6, respectively. Seedlots with relatively slow height growth (Figure 3) are associated with lesser shoot mass (Figure 6) and relatively greater root mass until mid-October (Figure 5). The most vigorous seedlot in height growth, the hybrid seedlot 3958, produced the greatest shoot mass and, until late September, relatively little root mass (Figure 5). In the 2 weeks before lift, seedlots 3958, 5261 and 8482 increased root mass sharply while the other seedlots showed reduced or constant root mass (Figure 5). Seasonal deviations aside, root mass generally increased in control seedlings until the time of lift.

3.1.2 Short-day treatment seedling growth

Short-day treatments initiated on July 6 resulted in swift and consistent decreases in rate of height extension and attainment of final height. Similar results have been reported by Arnott *et al.* (1988) for hemlock. Figures 7–12 show the effect of 2-, 4-, and 6-week duration short-day treatments on height extension of the six seedlots tested.

With the occasional exception of the hybrid Sitka-white spruce seedlot (Figure 12), results can be generalized as follows. After 2 weeks of short-day treatment (Figures 7–12), all seedlots showed reduced height compared to that in untreated controls. Reductions were greatest with the shortest photoperiod treatment (13 h) and least with the 17-h treatment. In three of the six seedlots, the height response to 13- and 15-h treatments was very similar. In all seedlots there was a consistent progression of height control with shortened photoperiod.

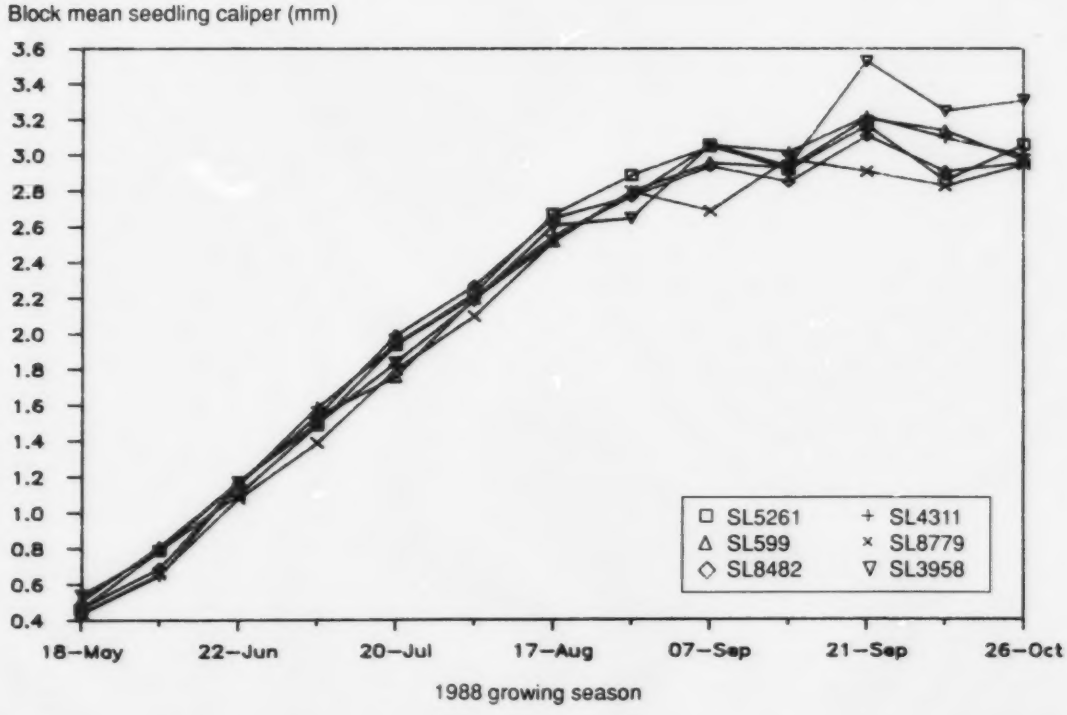

FIGURE 4. Block mean seedling root collar diameter of control (ambient photoperiod) treatment seedlots in the 1988 growing season. Points graphed are the mean of 18–54 seedlings.

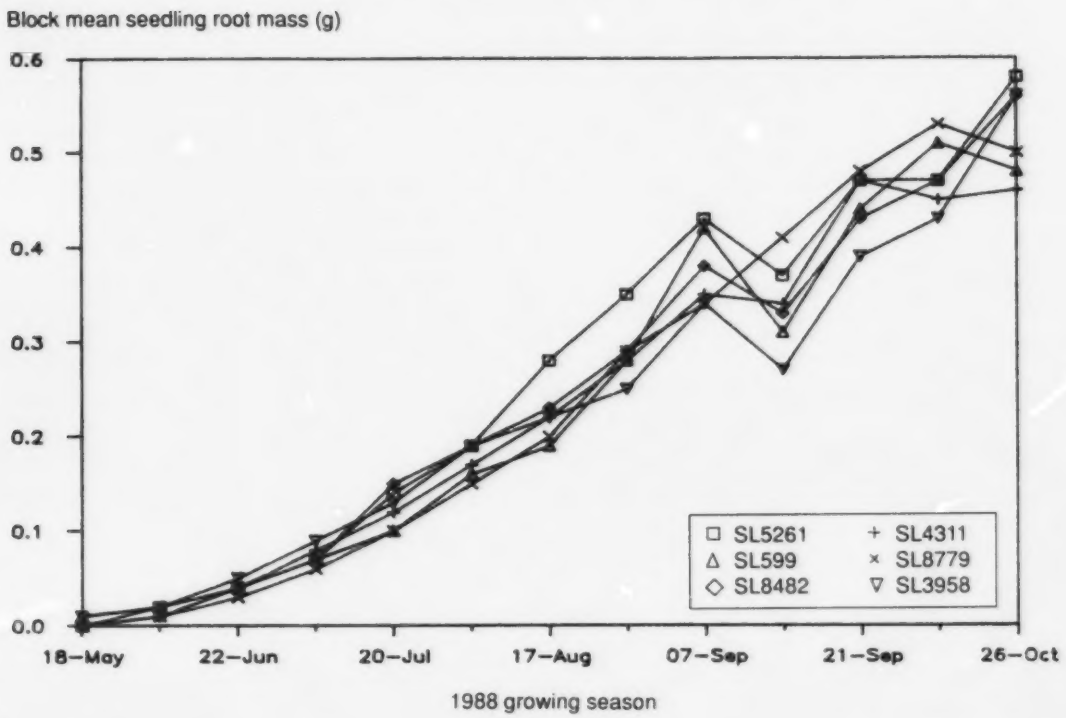

FIGURE 5. Block mean seedling root mass of control (ambient photoperiod) treatment seedlots in the 1988 growing season. Points graphed are the mean of 18–54 seedlings.

The treatment pattern observed within seedlots after 2 weeks of treatment remained largely unchanged after 4 and 6 weeks (Figures 7–12). There was an increasing trend to pairing of the 19- and 17-h, and the 15- and 13-h, treatments. In seedlots 5261, 4311, 8482 and 8779, either 13- or 15-h treatments for 6 weeks brought about a similar degree of height control. The range of final heights was greatest in the vigorous hybrid seedlot (Figure 12), and the greatest differences showed up between the 19- and 17-h and the 15- and 13-h treatment groups. Overall, good height control was achieved with relatively long photoperiods (13 and 15 h) applied for short and intermediate (2 and 4 week) durations.

The height increment that can be expected to follow short-day treatments is of importance to growers who must produce seedlings within certain contractual height standards. It is equally important for culturists who must be aware of the relationships between shoot extension and carbon allocation patterns. Table 6 gives the mean seedling height increment following short-day treatment by treatment and seedlot. Height increments from the most severe blackout treatments were roughly one-half that of the control over all seedlots. The range in seedling increment was 39–128 mm for the white and Engelmann spruce seedlots, and 88–217 mm for the hybrid Sitka spruce (Table 6). Analysis of these data confirmed the strong effect of the hybrid Sitka-white spruce seedlot, already noted, on first-order interaction terms (data not presented). An *a posteriori* decision was made to delete this seedlot from the overall analysis presented in Table 7 for ease of interpretation.

All treatment main effects (P, D, and S) were significant (Table 7), but photoperiod was the most significant. None of the first-order interactions were significant (P=0.95), when the hybrid seedlot was excluded. Mean increments following short-day treatment were 102, 80, 59 and 51 mm for the 19-,

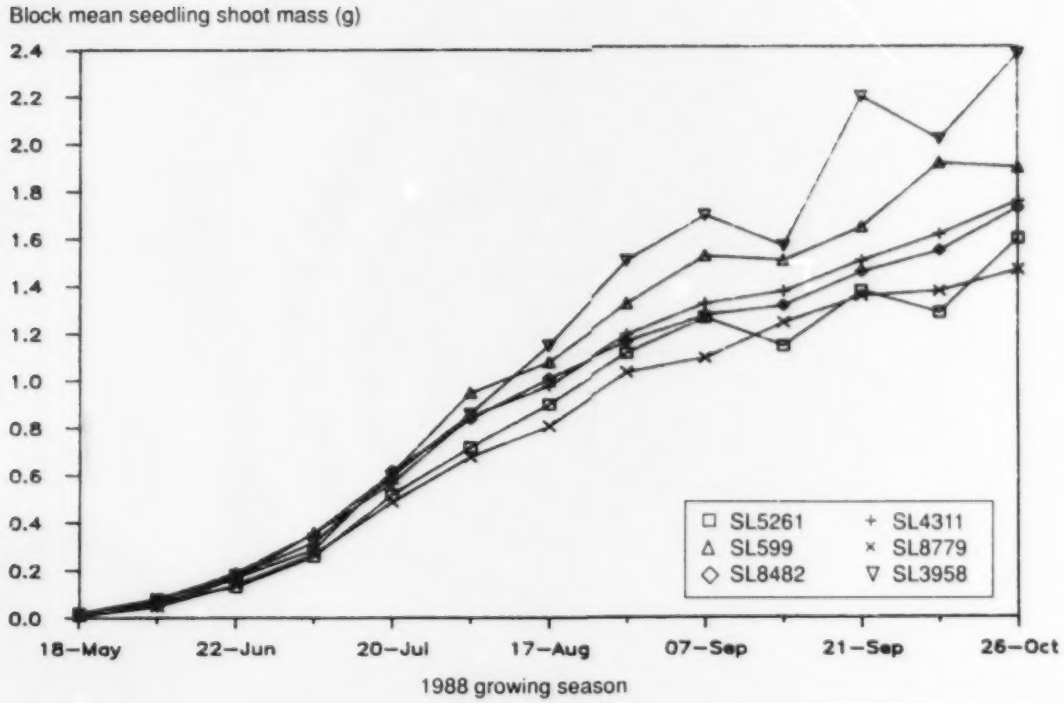

FIGURE 6. Block mean seedling shoot mass of control (ambient photoperiod) treatment seedlots in the 1988 growing season. Points graphed are the mean of 18–54 seedlings.

17-, 15- and 13-h photoperiod treatments, respectively (Table 8). In terms of the average white and Engelmann spruce height at time of treatment (79 mm), this amounts to a 130, 100, 75 and 63% increment, or continued height extension following 19-, 17-, 15- and 13-h treatments, respectively.

Duration main effects, although statistically significant (Table 7), were small and somewhat inconsistent (Table 8). After excluding the hybrid spruce, duration main effect means ranged from 70 mm (4 weeks) to 76 mm (6 weeks), with the 2-week treatment being intermediate. This range is not considered to be practically significant.

Seedlot height increment means fell into two significantly different groups, with SL5261 and SL8779 averaging 64 mm, and the other white and Engelmann spruce seedlots 79 mm (Table 8). The lack of separation along species lines could mean that height increment is not a strongly regulated characteristic, or that the common nursery environments limit the range of seedlot phenotypic expression.

Short-day treatments affected not only the height increment of seedlings, but also the variability of increment. This has also been reported by Olson *et al.* (1959). For all six seedlots, the coefficient of variation (CV) for the control treatment increment (19 h; pooled 2-, 4- and 6-week duration) averaged 45% (Table 9). By contrast, the most severe short-day treatment (13 h for 6 weeks) had the smallest CV (31%). Variation in height increment tended to decrease with decreasing photoperiod and increasing duration of treatment (Table 9). However, combinations of longer photoperiod treatments and short durations (e.g., 15-h 2-week and 17-h 2-week durations) resulted in increment variability greater than in the controls. The reason for this variability is the interaction of these intermediate severity treatments with individual tree size or physiological vigour.

TABLE 6. Seedling height increment mean (July 6 – October 26) and standard deviation (bracketed) by seedlot and short-day treatment. n = 10 trees per treatment. Hours – h; weeks – wk.

	Seedlot height increment (mm)					
Short-day treatment	**SL5261**	**SL4311**	**SL8482**	**SL599**	**SL8779**	**SL3958**
13 h 2 wk	44 (14.0)	56 (6.9)	48 (12.6)	51 (5.0)	50 (11.3)	105 (28.0)
15 h 2 wk	58 (6.8)	58 (13.4)	67 (11.0)	81 (16.6)	45 (13.5)	166 (63.3)
17 h 2 wk	66 (22.3)	87 (32.2)	85 (14.0)	91 (17.8)	78 (22.4)	199 (61.3)
19 h 2 wk	80 (24.7)	116 (41.4)	87 (30.8)	116 (27.2)	85 (30.7)	204 (61.1)
13 h 4 wk	39 (9.3)	58 (6.9)	57 (5.8)	52 (10.8)	50 (9.0)	93 (7.9)
15 h 4 wk	52 (9.1)	61 (11.2)	67 (10.6)	68 (7.6)	49 (9.3)	113 (25.6)
17 h 4 wk	62 (9.9)	65 (13.9)	74 (13.1)	85 (15.4)	68 (10.5)	176 (41.0)
19 h 4 wk	74 (38.6)	128 (42.0)	107 (19.6)	96 (20.9)	84 (30.5)	217 (51.5)
13 h 6 wk	51 (10.7)	55 (11.9)	50 (10.8)	55 (7.3)	45 (4.7)	88 (13.4)
15 h 6 wk	45 (7.5)	66 (20.5)	61 (9.4)	60 (11.8)	54 (8.2)	116 (23.1)
17 h 6 wk	75 (13.9)	89 (16.2)	95 (15.1)	87 (18.7)	86 (22.2)	197 (49.3)
19 h 6 wk	99 (25.3)	110 (38.5)	123 (39.3)	126 (24.3)	98 (36.9)	192 (38.8)

TABLE 7. ANOVA of seedling height increment (July 6 – October 26) by short-day treatment excluding the hybrid spruce seedlot (3958). Probability of greater F value by chance – P>F.

Source	**df**	**Mean square**	**F value**	**P>F**
Photoperiod	3	7850	84.5	0.0001
Duration	2	214	5.4	0.0323
Seedlot	4	849	14.4	0.0001
P x D	6	142	2.4	0.0570
P x S	12	92	1.6	0.1660
S x D	8	39	0.7	0.7137
Error	24	1417		

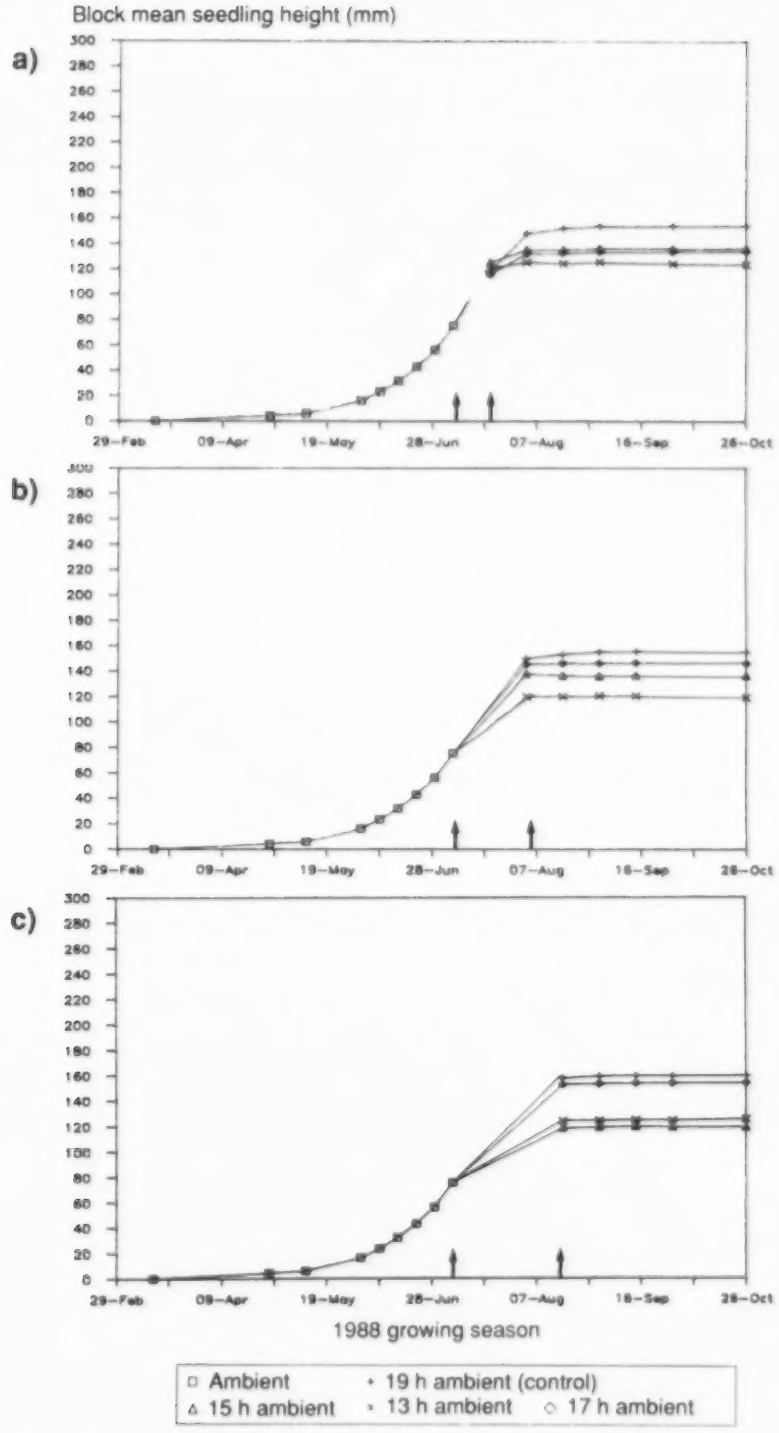

FIGURE 7. Seedlot 5261 height growth response to short-day treatments. All seedlings were grown under ambient conditions until July 6, then treated for (a) 2 weeks, (b) 4 weeks, or (c) 6 weeks, after which they were returned to ambient photoperiod. Arrows indicate blackout treatment application duration. Points graphed are the mean of 60 trees.

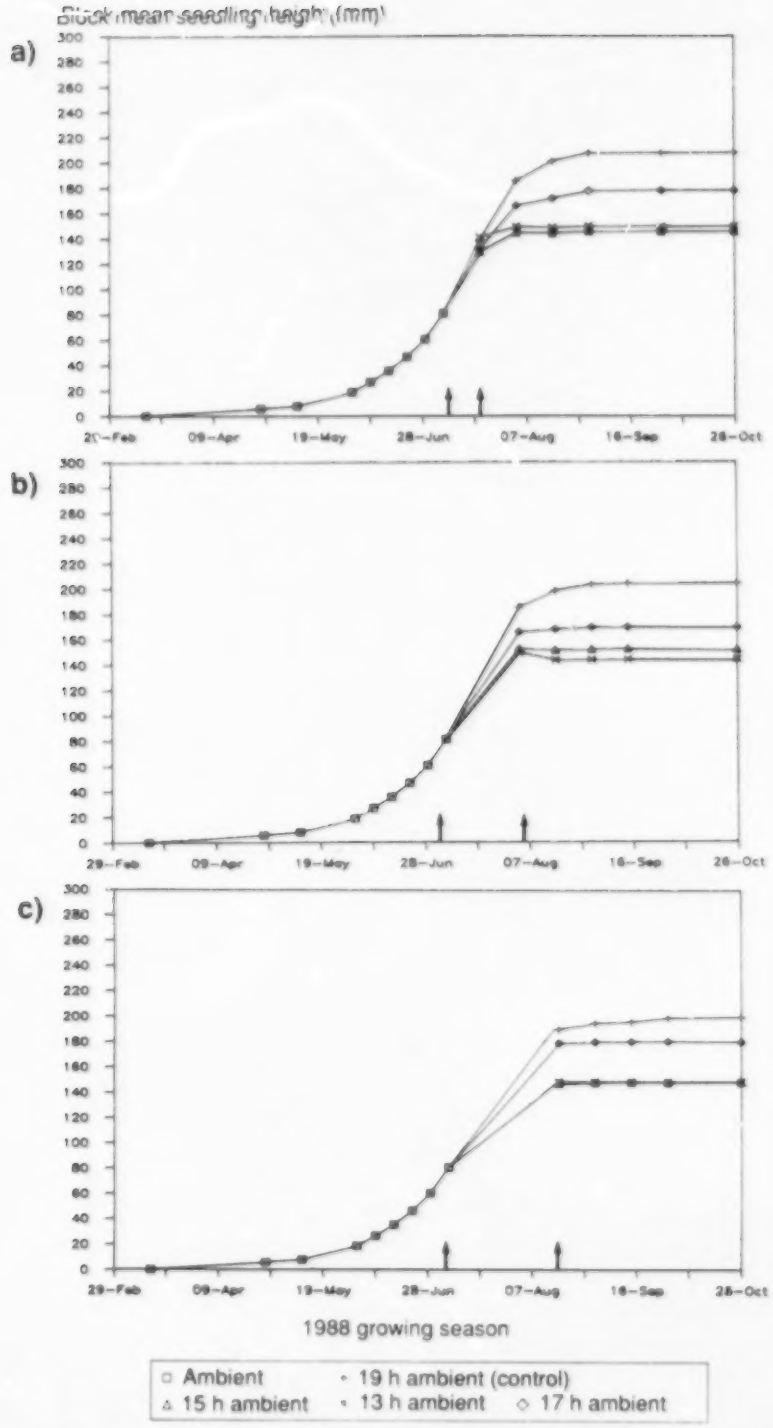

FIGURE 8. Seedlot 4311 height growth response to short-day treatments. All seedlings were grown under ambient conditions until July 6, then treated for (a) 2 weeks, (b) 4 weeks, or (c) 6 weeks, after which they were returned to ambient photoperiod. Arrows indicate blackout treatment application duration. Points graphed are the mean of 60 trees.

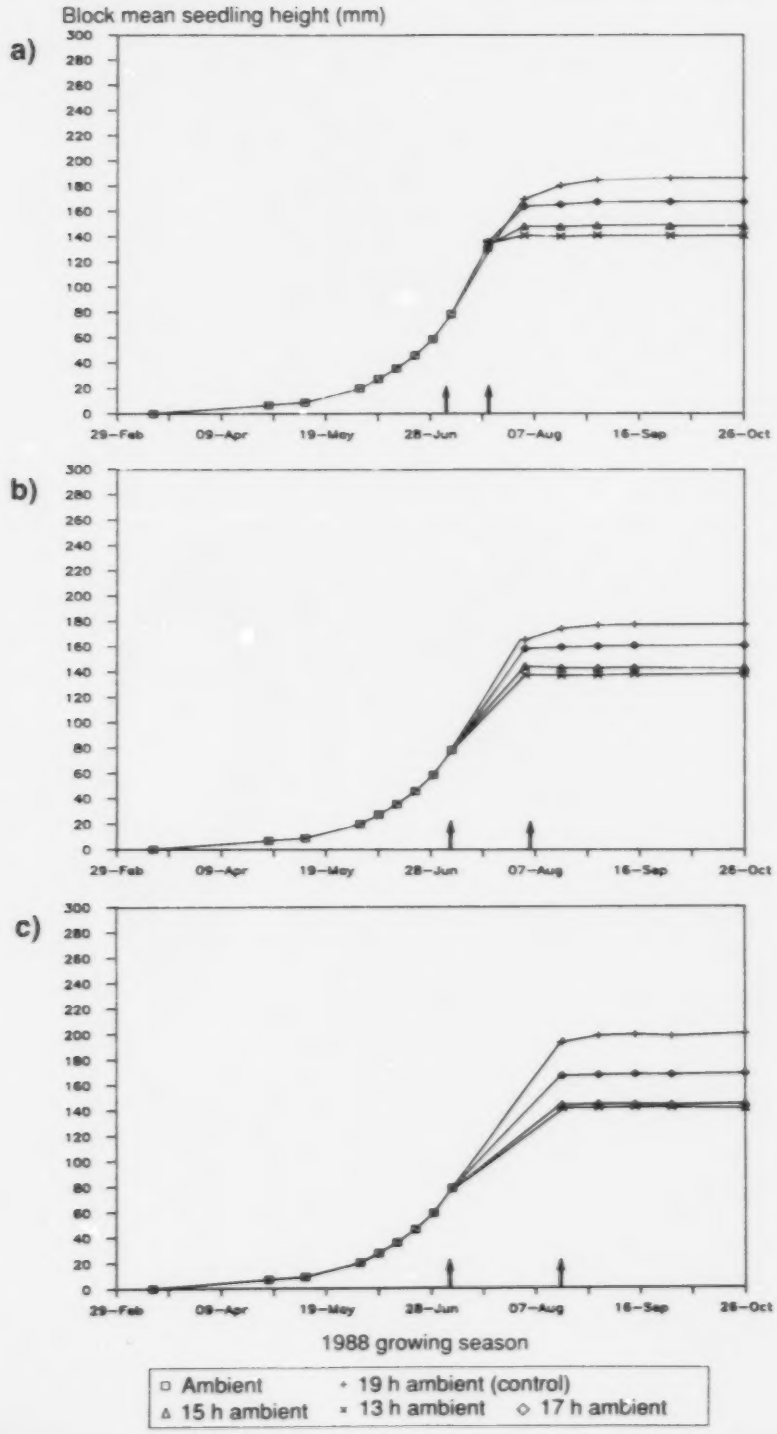

FIGURE 9. Seedlot 8482 height growth response to short-day treatments. All seedlings were grown under ambient conditions until July 6, then treated for (a) 2 weeks, (b) 4 weeks, or (c) 6 weeks, after which they were returned to ambient photoperiod. Arrows indicate blackout treatment application duration. Points graphed are the mean of 60 trees.

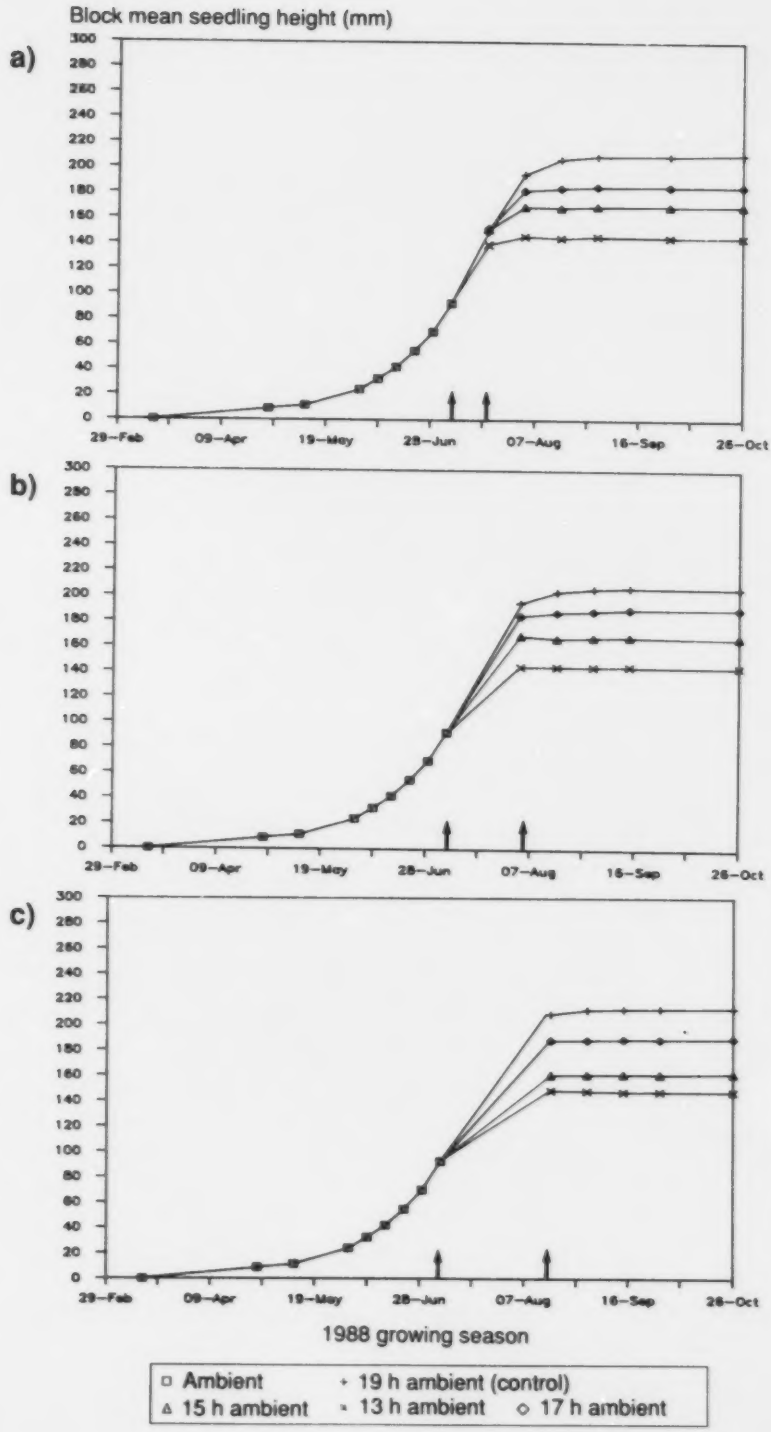

FIGURE 10. Seedlot 599 height growth response to short-day treatments. All seedlings were grown under ambient conditions until July 6, then treated for (a) 2 weeks, (b) 4 weeks, or (c) 6 weeks, after which they were returned to ambient photoperiod. Arrows indicate blackout treatment application duration. Points graphed are the mean of 60 trees.

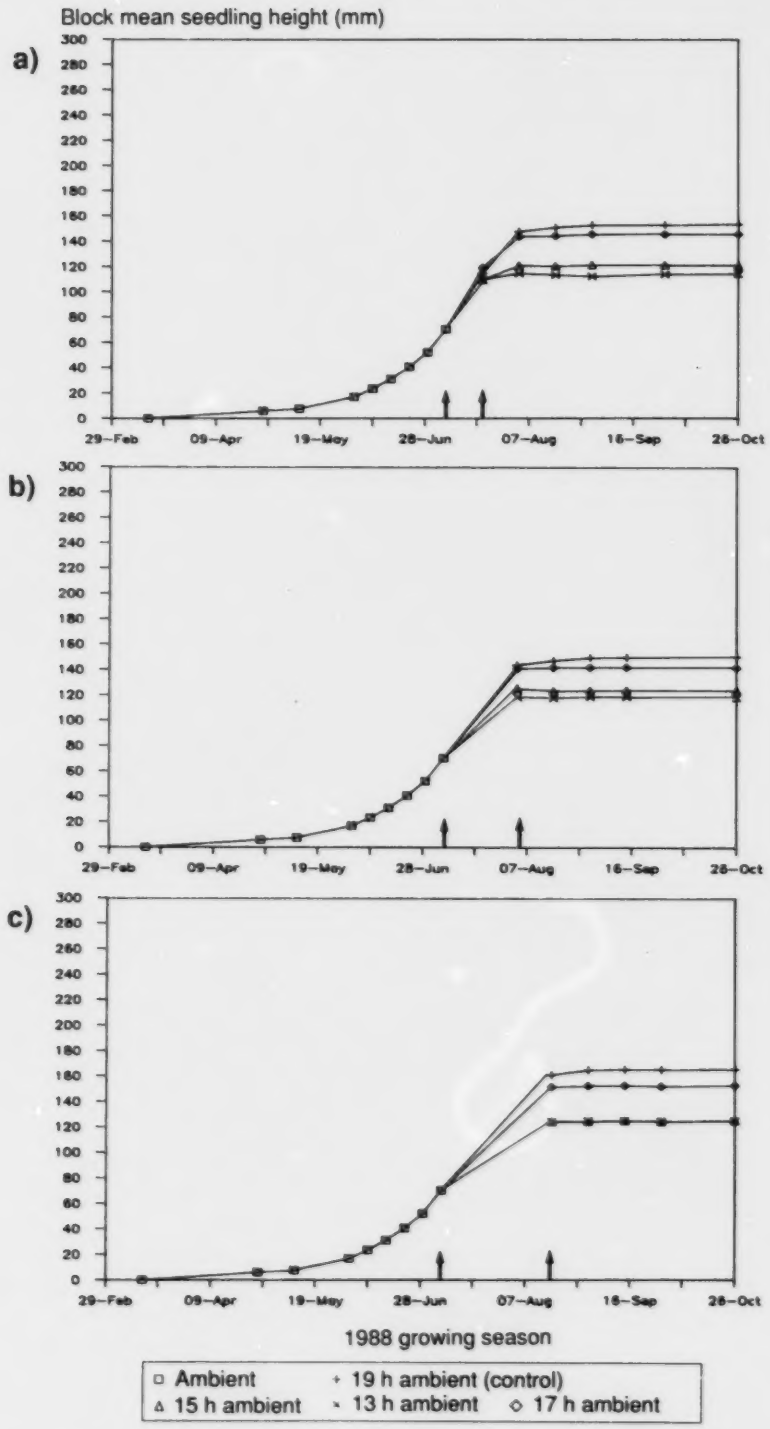

FIGURE 11. Seedlot 8779 height growth response to short-day treatments. All seedlings were grown under ambient conditions until July 6, then treated for (a) 2 weeks, (b) 4 weeks, or (c) 6 weeks, after which they were returned to ambient photoperiod. Arrows indicate blackout treatment application duration. Points graphed are the mean of 60 trees.

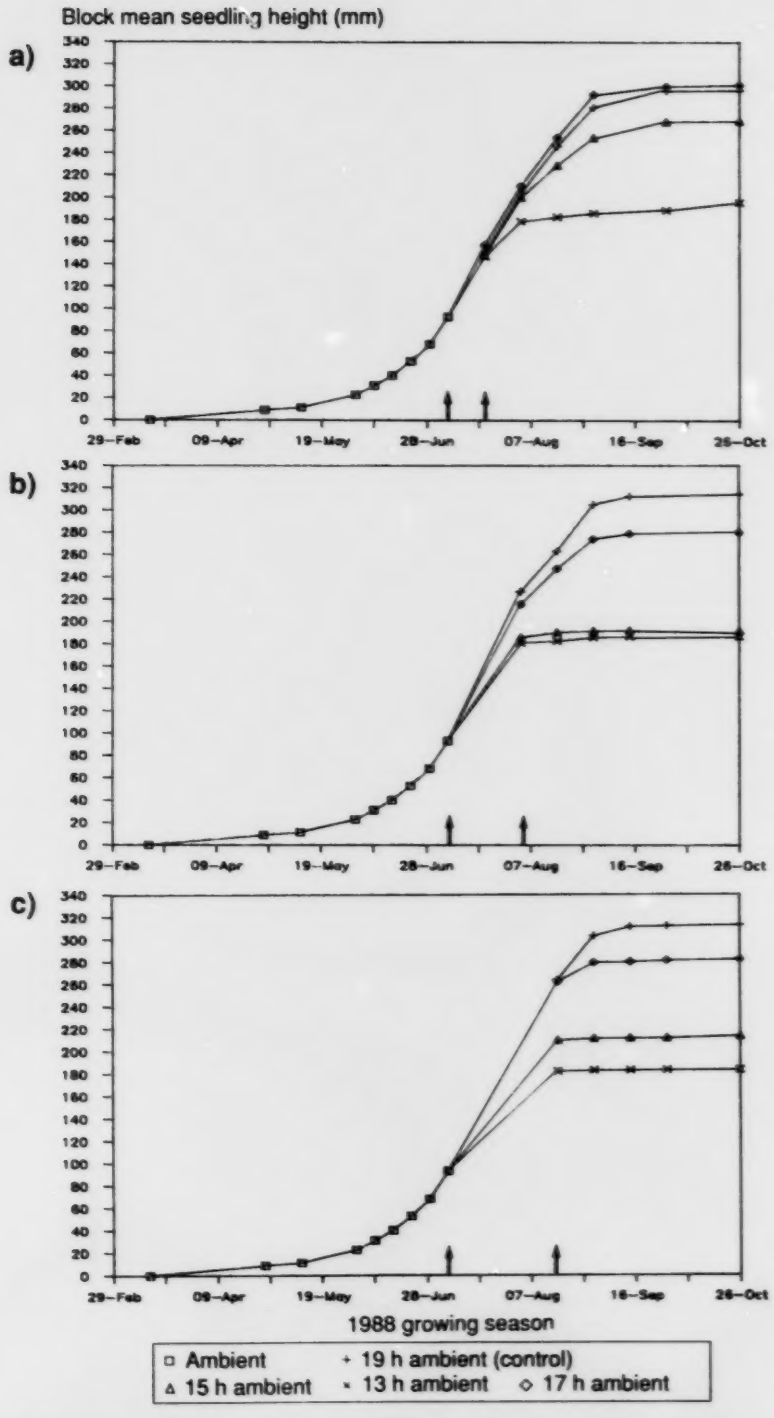

FIGURE 12. Seedlot 3958 height growth response to short-day treatments. All seedlings were grown under ambient conditions until July 6, then treated for (a) 2 weeks, (b) 4 weeks, or (c) 6 weeks, after which they were returned to ambient photoperiod. Arrows indicate blackout treatment application duration. Points graphed are the mean of 60 trees.

When end-of-season individual seedling height is plotted against initial (pre-treatment) height, the relationship between photoperiod treatments is clear (Figure 13). All durations are pooled and the hybrid Sitka-white spruce seedlot excluded from this data set. Analysis of covariance comparing photoperiod regression line slopes and intercepts (Snedecor and Cochran 1967) determined both to be significant (Table 10).

TABLE 8. Seedling height increment means and Duncan's multiple range tests (DMRT) by photoperiod, duration, and seedlot. Mean values followed by the same letter within a main effect are not significantly different (P=0.95).

Photoperiod (n=15)	Duration (n=20)	Seedlot (n=12)	Mean (mm)	DMRT
19 h			102	a
17 h			80	b
15 h			59	c
13 h			51	d
	6 week		76	a
	2 week		72	ab
	4 week		70	b
		SL599	81	a
		SL4311	79	a
		SL8482	77	a
		SL8779	66	b
		SL5261	62	b

TABLE 9. Seedling height increment (July 6–October 26) mean, standard deviation (SD), coefficient of variation (CV), and sample size (n) by short-day treatment for all seedlots pooled. Hour – h; weeks – wk.

Short-day treatment	Seedling height increment (mm)				
	Mean	SD	CV	Range	n
13 h 2 wk	60	25.6	43.0	139	57
13 h 4 wk	59	18.7	31.9	80	52
13 h 6 wk	57	17.4	30.5	83	59
15 h 2 wk	80	49.5	61.9	246	58
15 h 4 wk	70	25.1	36.1	122	57
15 h 6 wk	66	26.5	39.8	109	58
17 h 2 wk	99	53.3	53.6	271	58
17 h 4 wk	88	45.1	50.9	226	59
17 h 6 wk	106	49.7	46.9	231	57
19 h 2 wk	116	56.6	49.0	278	59
19 h 4 wk	118	59.2	50.1	300	59
19 h 6 wk	125	46.5	37.1	225	56

TABLE 10. Analysis of covariance of final, over pre-treatment, seedling height by photoperiod treatment. All durations are pooled within a photoperiod treatment and the Sitka hybrid seedlot is excluded. Results are based on the serial measurements of approximately 140 seedlings per photoperiod. Abbreviations: P, photoperiod treatment in hours; df, degrees of freedom; a, Y intercept; b, slope of line; SS, sum of squares; MS, mean square; R^2, coefficient of determination; RMSE, root mean square error; and P>F, probability of F greater by chance.

P	df	a	b	SS	MS	R^2	RMSE	P>F
13	138	14.46	1.44	8 128.92	59.34	0.89	7.7	0.0001
15	143	13.77	1.57	15 986.33	112.58	0.87	7.6	0.0001
17	144	23.97	1.70	38 782.77	271.21	0.74	16.5	0.0001
19	182	27.58	1.96	156 084.44	862.34	0.61	29.4	0.0001

Difference between slopes F = 2395/363 = 6.6 (3, 603 df). P>0.0002.
Difference between intercepts F = 98151/373 = 263 (3,603 df). P>0.0001.

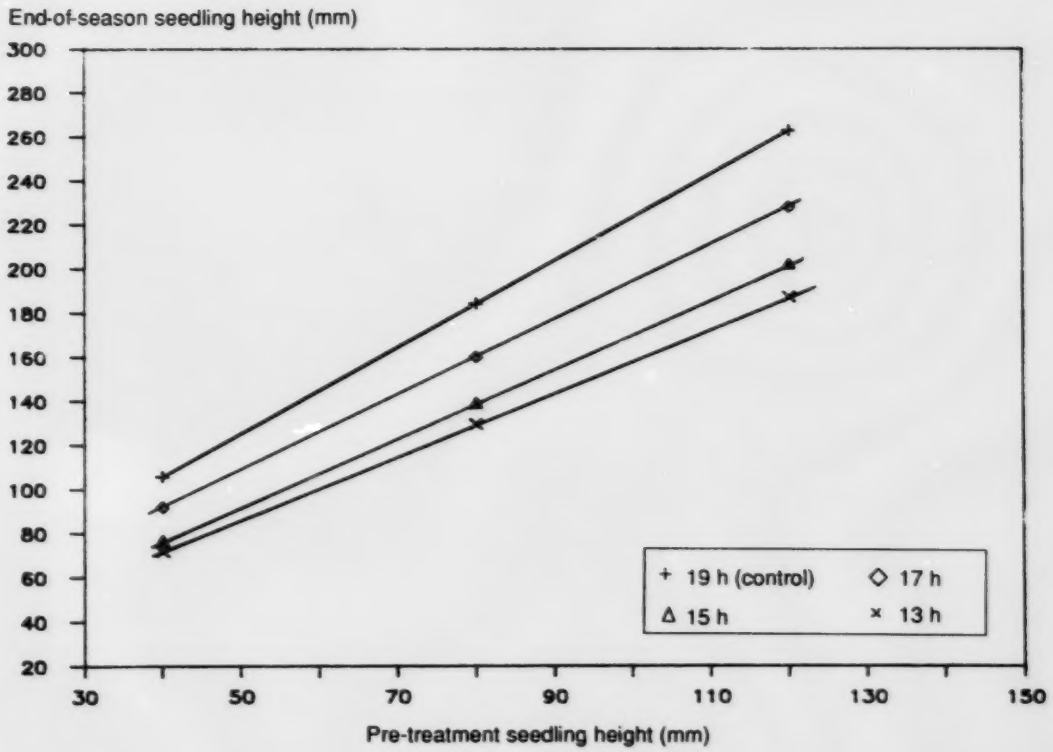

FIGURE 13. Relationships between end-of-season individual seedling height and pre-treatment (July 06) height by photoperiod, all durations and white and Englemann seedlots pooled. Results are based on the repeated measurement of approximately 140 seedlings per photoperiod.

Post-treatment seedling height increment depends on photoperiod treatment, with greater increments being associated with increasing day length. Relatively small seedlings at time of treatment grew relatively less following treatment. The greatest variation was found under long day lengths (ambient); the least variation was found following short-day treatment (Table 10).

Based on these projected increments for pooled white and Engelmann spruce seedlots, the pre-treatment seedling height required to achieve contractual minimum, maximum and target heights in 1988 at RRRS were calculated (Table 11). These data indicate that the more severe the short-day treatment, the taller the seedlings can be before treatment application. In addition, an increase in seedling height uniformity can be expected (Table 10).

TABLE 11. Estimated seedling height required prior to short-day treatment (July 6) to give minimum (120 mm), target (170 mm), and maximum (250 mm) final seedling height (October 26). Based on 1988 white and Engelmann spruce data from RRRS with treatment durations pooled, averaging 4 weeks.

	Pre-treatment (July 6) seedling height (mm) to give:		
Short-day treatment	**Minimum (120 mm)**	**Target (170 mm)**	**Maximum (250 mm)**
13 h 4 wk	73	108	164
15 h 4 wk	68	100	150
17 h 4 wk	56	86	133
19 h 4 wk (ambient)	47	73	113

3.1.3 Seasonal seedling nutrient status

Most macroelements were in their optimal range over the course of the nursery season (Table 12). Phosphorus was present in high to excessive levels over most of the season, though not at toxic levels (Marschner 1986), while Mg and K were at excessive concentrations early in the season but were optimal for the remainder. The N:S ratio (not presented) was in the 9–10 range, indicating a good balance for N and S.

Microelements were generally in their optimal range over the nursery season (Table 12). Iron and Mn were sub-optimal before short-day treatments, but maintained good levels for the balance of the season. Zinc and B were present in supra-optimal concentrations towards the end of the season. The Zn concentration did not approach toxic levels of 400–500 ppm (White *et al.* 1979) and therefore root elongation was likely not affected (Godbold *et al.* 1983). Boron, the least understood of all mineral nutrients (Marschner 1986), did not approach toxic levels found even in the most sensitive (100 ppm) plants (El-Sheikh *et al.* 1971).

Overall, season mineral nutrition was acceptable. Any growth alterations observed under field conditions can probably be attributed to short-day and duration treatment effects, rather than to nutritional imbalances. However, the effects of high end-of-season Zn and B concentrations on subsequent field growth have yet to be determined.

3.2 End of 1988 Nursery Growing Season

3.2.1 Nursery morphology

Samples of 30 trees per short-day treatment were measured on October 26, 1988, to assess seedling height, RCD, and root, shoot and total plant mass. Analysis of these end-of-season data indicated, once again, the strong influence of the hybrid spruce seedlot on first- and second-order interaction terms (Table 13). Exclusion of the hybrid seedlot from analysis eliminated five significant interaction terms and

TABLE 12. Seasonal macro- and micronutrient content with all spruce seedlots, photoperiods and durations pooled during the 1988 nursery year at RRRS. There were no differences detected between photoperiod treatments. Above (a) and below (b) optimum range are as described by Northwest Soil Research Incorporated.

	Macroelements (%)					
Date	N	P	Ca	Mg	K	S
15 April	2.79	0.48 a	0.61	0.50 a	1.92	—
15 May	2.98	0.53 a	0.66	0.31 a	2.03 a	0.242
08 June	2.82	0.48 a	0.56	0.23	1.93	0.293
22 June	2.84	0.44 a	0.54	0.22	1.70	0.289
06 July	2.44	0.38	0.50	0.21	1.42	0.275
03 August	2.67	0.36	0.63	0.21	1.35	0.238
17 August	2.71	0.42	0.74	0.23	1.17	0.257
07 September	2.90	0.42	0.95	0.23	1.27	0.287
03 October	3.00	0.45 a	0.73	0.22	1.17	0.290
02 November	2.77	0.43	0.71	0.21	1.15	0.275

	Microelements (ppm)				
Date	Cu	Zn	Fe	Mn	B
15 April	18	114 a	472	164	28
15 May	5	26	507	93	39
08 June	4	56	80	72 b	32
22 June	7	47	76 b	80	37
06 July	6	43	130	198	52
03 August	6	64	289	262	48
17 August	8	73	189	325	55 a
07 September	10	94 a	265	463	59 a
03 October	9	137 a	312	641	61 a
02 November	9	100 a	381	633	59 a

TABLE 13. Summary of end-of-season (October 26) seedling height, caliper, root, shoot, and plant mass ANOVA. NS – non-significant ($P<0.95$); S – significant ($P\geq0.95$). Brackets indicate a change in significance with the exclusion of the hybrid spruce (3958) seedlot from the analysis.

			Mass		
Source	Height	Caliper	Root	Shoot	Plant
Photoperiod	S	S	NS	S	S
Duration	NS	S	(S)	S	S
Seedlot	S	S	S	S	S
P x D	NS	S	(NS)	NS	NS
P x S	S	(S)	NS	(S)	NS
D x S	(S)	NS	NS	(S)	NS
P x D x S	(S)	NS	NS	NS	NS

caused one non-significant term to become significant. As well, significant photoperiod and duration main effects on root mass (Table 13) became insignificant with the hybrid spruce excluded. For ease of analysis and interpretation, the five white and Engelmann spruce seedlots were considered as a group separate from the Sitka-white spruce hybrid seedlot.

Photoperiod had a significant effect on seedling final height with or without inclusion of the hybrid seedlots (Table 13). Short-day treatment height means in Figure 14 show clearly that short days reduced final crop height for all seedlots, but that the effect was greatest for the hybrid spruce seedlot (Figure 14). Without the hybrid seedlot, only the PxS interaction is significant (Table 13) and this interaction is small in practical terms (Figure 14).

Duration main effects on end-of-season height are non-significant overall (Table 13 and Figure 14). Two weeks of short days were as effective as 4 or 6 weeks in terms of final seedling height. Although the duration main effect on height is not significant, a trend to increased height control with increased treatment duration can be seen in the more vigorous seedlots (Figure 14) at intermediate photoperiod levels. This gives rise to a significant DxS and PxDxS interaction when the hybrid spruce is included in the analysis.

The effect of seedlot on final height was reduced when the hybrid spruce was excluded, but remained significant (Table 13). Seedlots 3958, 599, 4311, 8482, 5261 and 8779 averaged 279, 190, 185, 175, 159 and 155 mm in final height, respectively (Figure 14). The more vigorous seedlots responded more to photoperiod and duration treatments.

Photoperiod, duration, and seedlot all significantly influenced end-of-season mean seedling RCD (Table 13). Photoperiod had the largest effect, followed by seedlot and duration. Photoperiod and seedlot interacted significantly only with the inclusion of the hybrid spruce. The photoperiod and duration interaction is ascribed to little or no duration effect at the 17-h photoperiod (or obviously at the ambient [19 h] photoperiod), and to relatively strong effects at the most extreme — 13-h — photoperiod (Figure 15). Seedling RCD tended to decrease with shorter photoperiods, but dropped most sharply in combination with long duration (4- and 6-week) treatments at the 13- and 15-h photoperiod (Figure 15). These findings differ from those of Arnott *et al.* (1988), who reported no effect of photoperiod on RCD.

Seedlot effects were significant on end-of-season RCD, with the hybrid seedlot (3958) having the largest RCD, followed by seedlots 4311, 5261, 8482, 599 and 8779 (Figure 15).

Root mass at season's end was strongly influenced by seedlot, but not by short-day treatment, within the white and Engelmann spruce seedlots (Table 13). Duration effects were small and weakly significant ($P>F=0.0339$) compared to seedlot effects ($P>F=0.0001$), and became non-significant with the inclusion of the hybrid spruce seedlot (Table 13). As was the case for RCD, there is evidence of decreasing root mass at 13- and 15-h photoperiods with increasing duration (Figure 16). This was most apparent in the white and Engelmann spruce seedlots 4311 and 8779 (Figure 16), and the PxD interaction became non-significant with inclusion of the hybrid (Table 13). Root mass at season's end averaged 600, 598, 538, 513, 499 and 485 mg for seedlots 3958, 5261, 8482, 4311, 8779 and 599, respectively. These mean root masses can be considered adequate to good for the 1988 growing season in the north.

Final shoot mass was strongly affected by photoperiod, duration, and seedlot (Table 13). The PxS and DxS interactions disappeared with exclusion of the hybrid seedlot. Shoot mass decreased with decreasing photoperiod, averaging 1797, 1643, 1492 and 1313 mg for 19-, 17-, 15- and 13-h photoperiods, respectively, over all seedlots and durations. Similarly, shoot mass decreased with increased treatment duration (Figure 17), averaging 1639, 1524 and 1520 mg for 2-, 4- and 6-week durations over all photoperiods and seedlots.

The hybrid spruce seedlot (3958) had the greatest mean shoot mass (1978 mg), followed by SL599 (1647 mg), SL4311 (1562 mg), SL8482 (1489 mg), SL5261 (1399 mg), and SL8779 (1291 mg). The shoot mass relationship between seedlots is similar to that for final height.

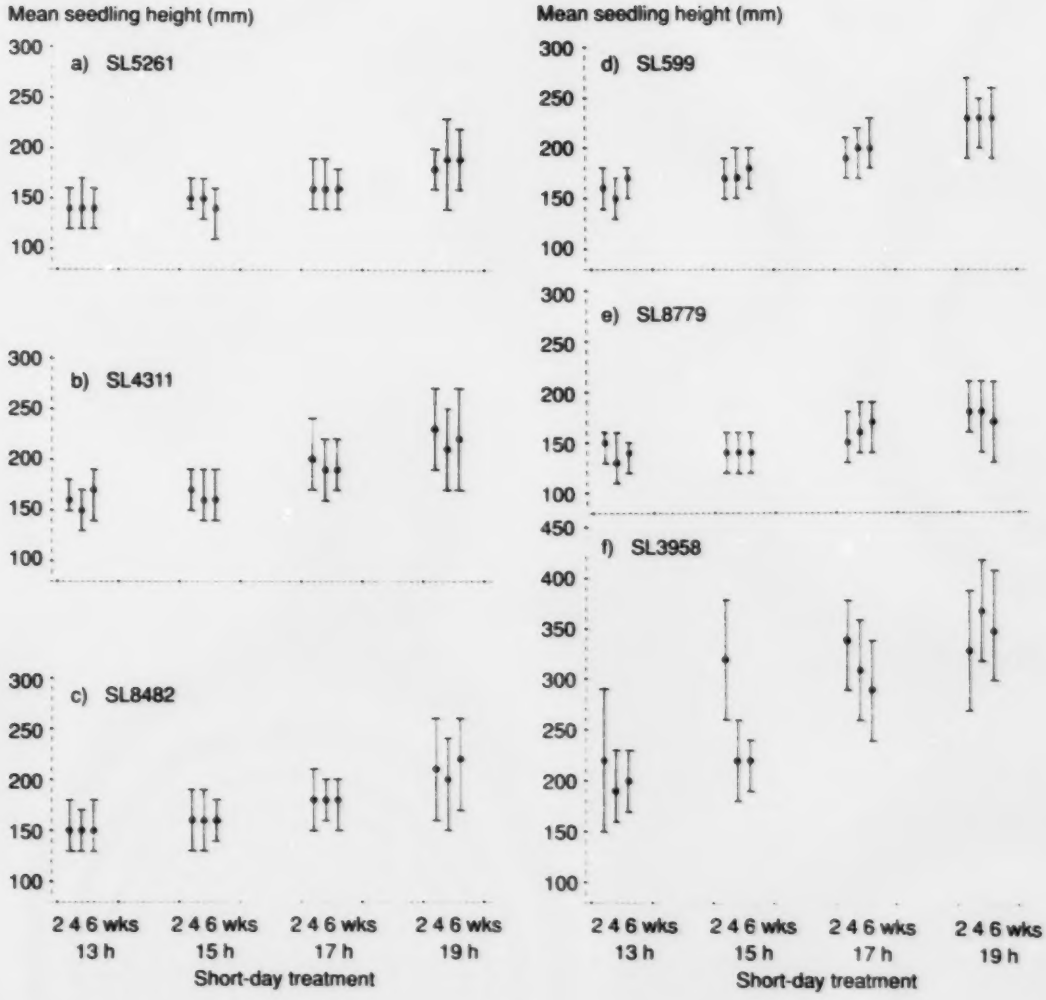

FIGURE 14. Mean seedling height (October 26) and standard deviation by short-day treatment and seedlot. Points graphed are the mean of 30 seedlings. a) SL5261, b) SL4311, c) SL8482, d) SL599, e) SL8779, and f) SL3958.

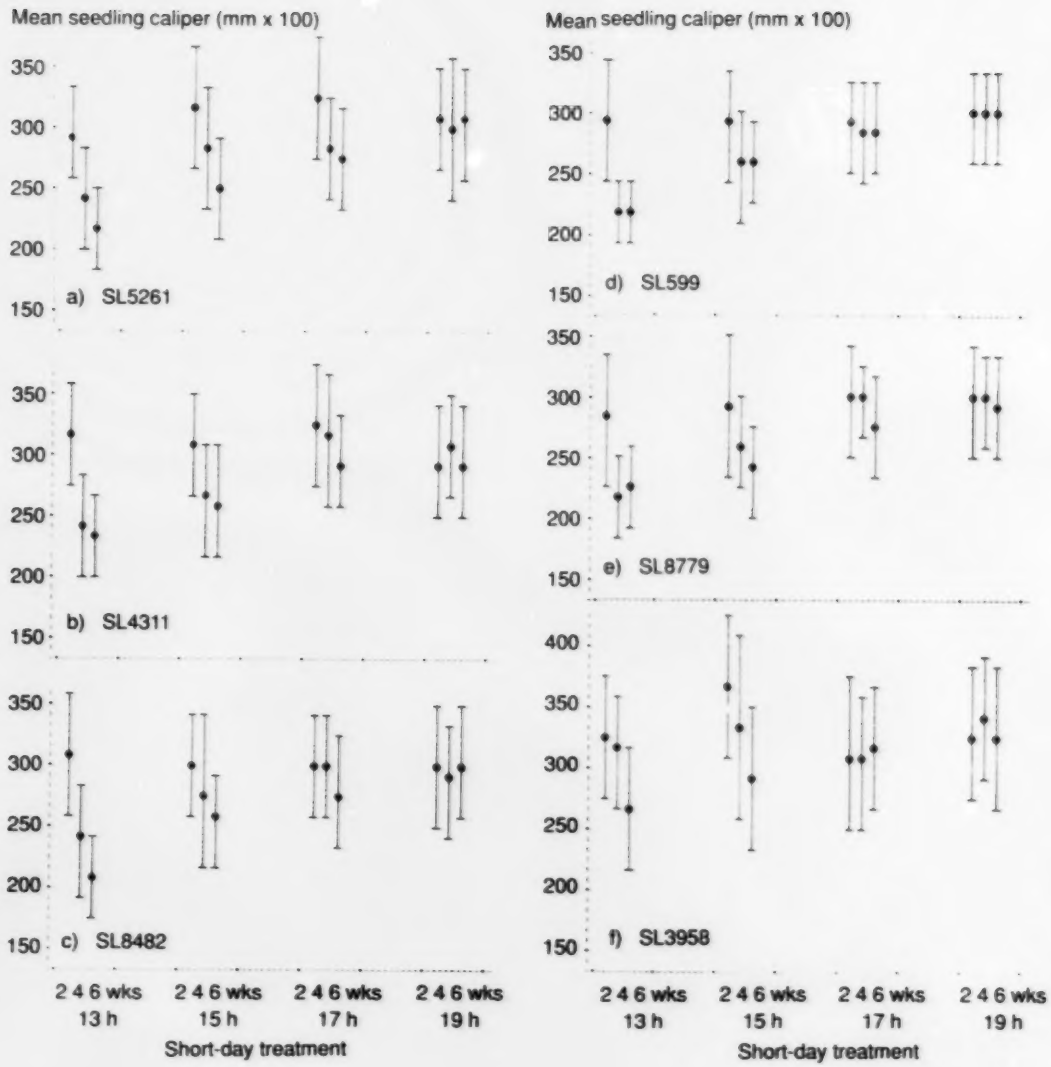

FIGURE 15. Mean seedling root collar diameter (October 26) and standard deviation by short-day treatment and seedlot. Points graphed are the mean of 30 seedlings. a) SL5261, b) SL4311, c) SL8482, d) SL599, e) SL8779, and f) SL3958.

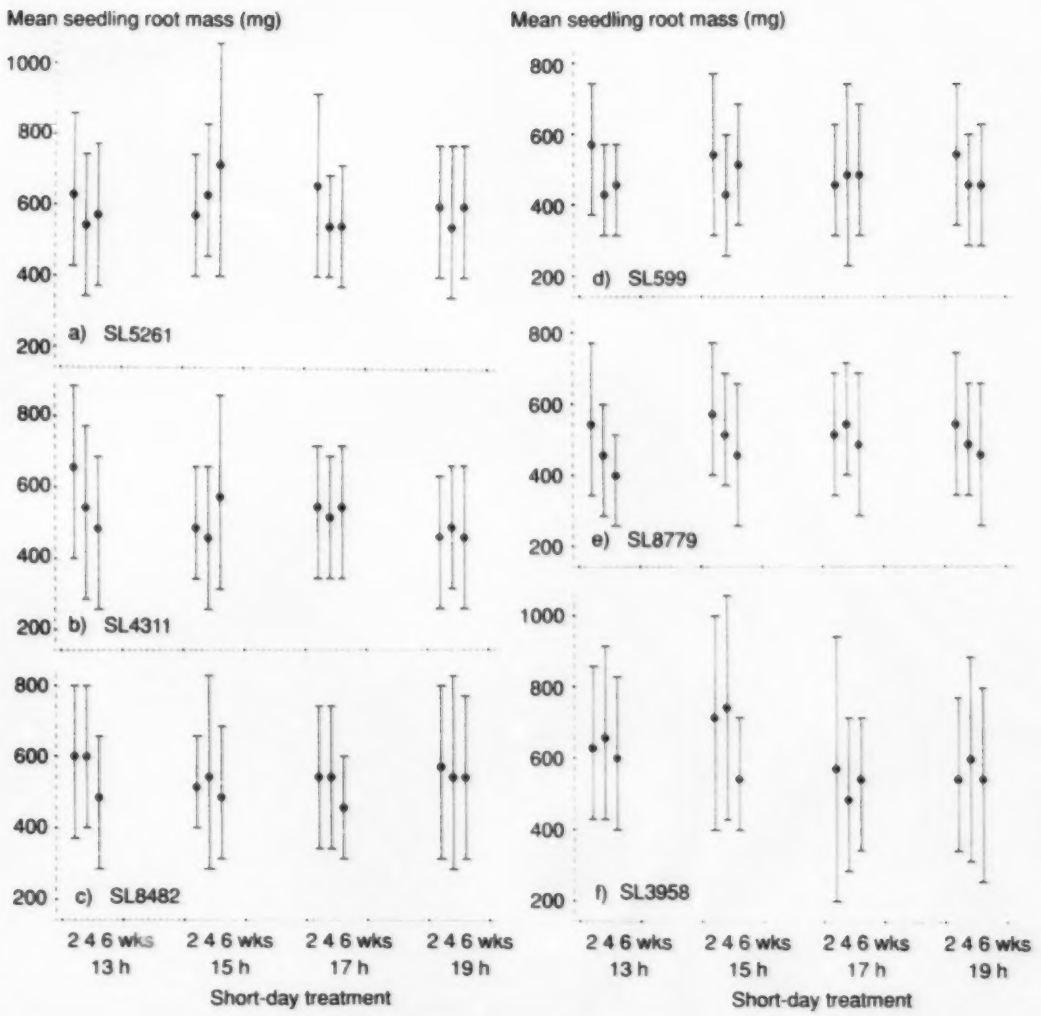

FIGURE 16. Mean seedling root mass (October 26) and standard deviation by short-day treatment and seedlot. Points graphed are the mean of 30 seedlings. a) SL5261, b) SL4311, c) SL8482, d) SL599, e) SL8779, and f) SL3958.

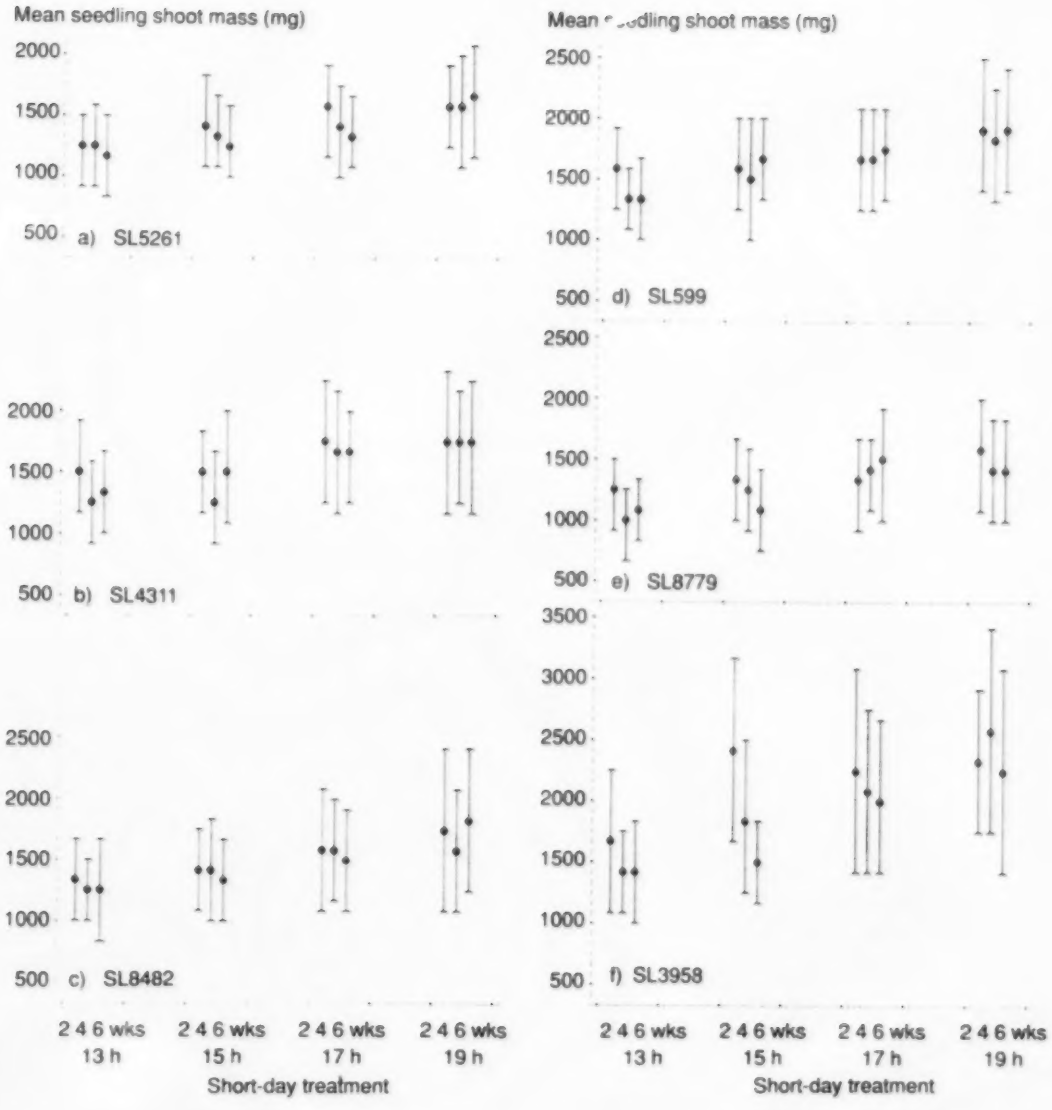

FIGURE 17. Mean seedling shoot mass (October 26) and standard deviation by short-day treatment and seedlot. Points graphed are the mean of 30 seedlings. a) SL5261, b) SL4311, c) SL8482, d) SL599, e) SL8779, and f) SL3958.

Total plant mass was significantly affected by photoperiod, duration, and seedlot (Table 13). End-of-season mass increased with increasing photoperiod from a minimum of 1860 mg at 13 h, to 2052, 2169 and 2319 mg at 15, 17 and 19 h, respectively (Figure 18). Plant mass response was similar to that of the shoot because of the relatively small effect of short-day treatment on end-of-season root mass. Duration effects ranged from 2205 mg of plant mass after 2 weeks, to 2060 and 2035 mg after 4 and 6 weeks, respectively.

Although statistically significant, this range is probably not of practical importance. If the 2-week treatment is considered as 100% plant mass, then 4 and 6 weeks are 93 and 92%, respectively. The dynamic application of blackout resulted in minimal losses of total plant mass, and thus achieved one of the project goals. The range in mean seedling mass between seedlots, however, was considerable. Seedlots 3958, 599, 4311, 8482, 5261 and 8779 averaged 2578, 2132, 2076, 2027, 1998 and 1790 mg total plant weight, respectively, primarily reflecting the different shoot mass values.

The above data indicate that while photoperiod, duration, and seedlot all had significant effects on seedling morphological variables, photoperiod itself had no effect on the final root mass. Loss of root mass has been one of the major concerns of short-day cultural treatments. These data suggest that root mass accumulation should not be an argument against the use of photoperiod treatment to control height in vigorous seedlots. It must be noted, however, that a direct test has not been done between static and dynamic applications of blackout. The above generalizations might not apply to stock treated with static blackout.

3.2.2 -18°C frost hardiness

On September 13, in all seedlots but the hybrid Sitka-white spruce, foliage browning results indicated that short photoperiod (13 h) and long duration (6 weeks) treatments resulted in enhanced foliage frost hardiness (Table 14). At this time, seedlots 8779 and 599 were the most advanced and 3958 the least advanced in acquiring foliar frost hardiness. The strong duration effect within a photoperiod was no longer evident by late September. For this reason, durations within a photoperiod were pooled when the fall changes in foliage frost hardiness were presented (Figure 19).

TABLE 14. Frequency of foliage browning (damage or death) following freezer testing for all PxDxS combinations grown at RRRS in 1988 and tested on September 13, 1988

		Seedlot					
P	D	5261	4311	8482	599	8779	3958
13 h	2 wk	0.75	0.95	0.70	0.15	0	1.00
13 h	4 wk	0.40	0.85	0.75	0	0	1.00
13 h	6 wk	0.20	0	0	0	0	1.00
15 h	2 wk	0.95	0.80	1.0	1.0	0.15	1.00
15 h	4 wk	0.95	0.95	0.85	0.50	0	1.00
15 h	6 wk	0.95	0.30	0.35	0	0	1.00
17 h	2 wk	1.00	1.0	1.00	0.80	0.60	1.00
17 h	4 wk	1.00	1.0	1.00	1.00	0.70	1.00
17 h	6 wk	0.80	1.0	0.95	1.00	0.60	1.00
19 h	2 wk	1.00	1.0	1.00	1.00	0.80	1.00
19 h	4 wk	1.00	0.95	1.00	1.00	1.00	1.00
19 h	6 wk	1.00	1.0	1.00	1.00	0.85	1.00

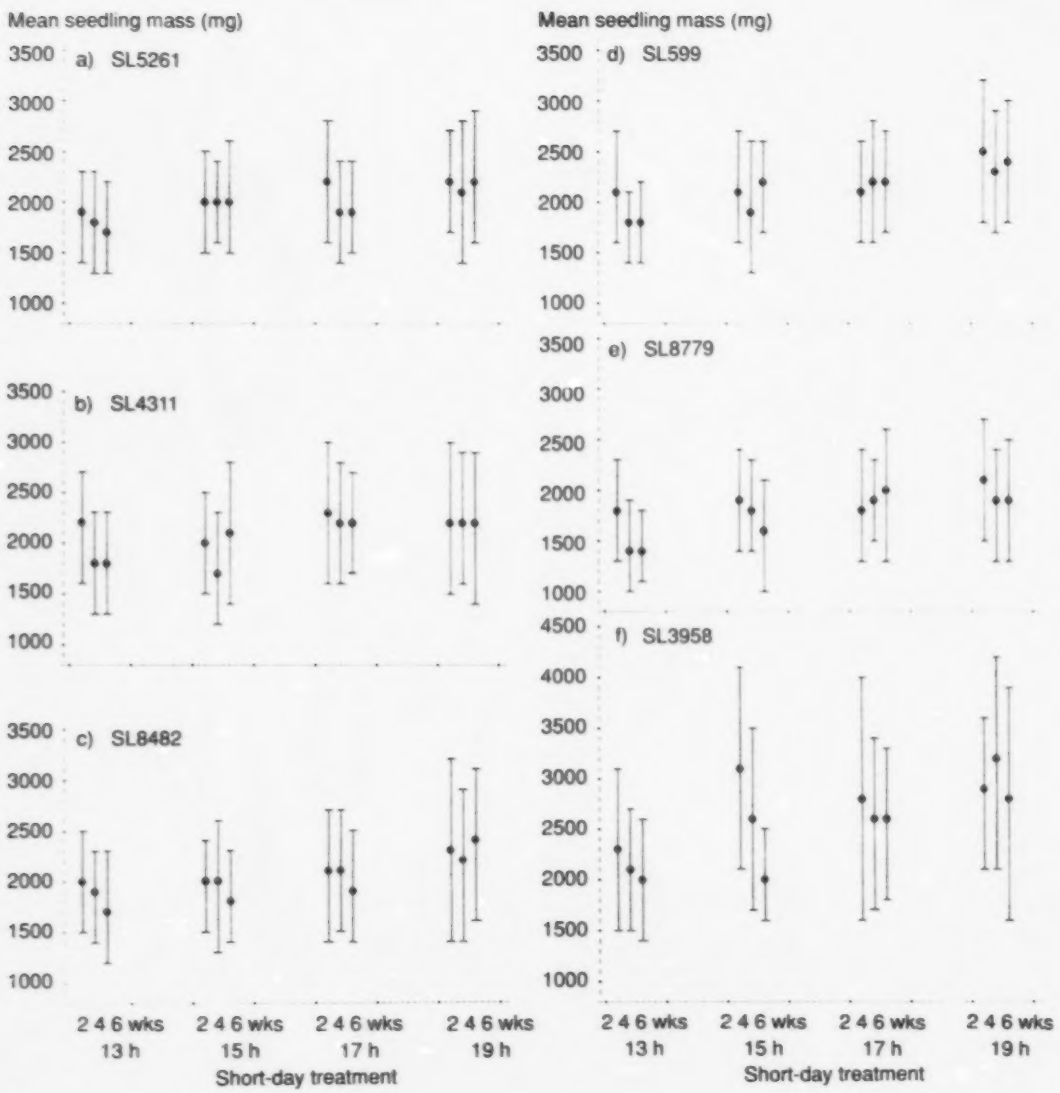

FIGURE 18. Mean seedling plant mass (October 26) and standard deviation by short-day treatment and seedlot. Points graphed are the mean of 30 seedlings. a) SL5261, b) SL4311, c) SL8482, d) SL599, e) SL8779, and f) SL3958.

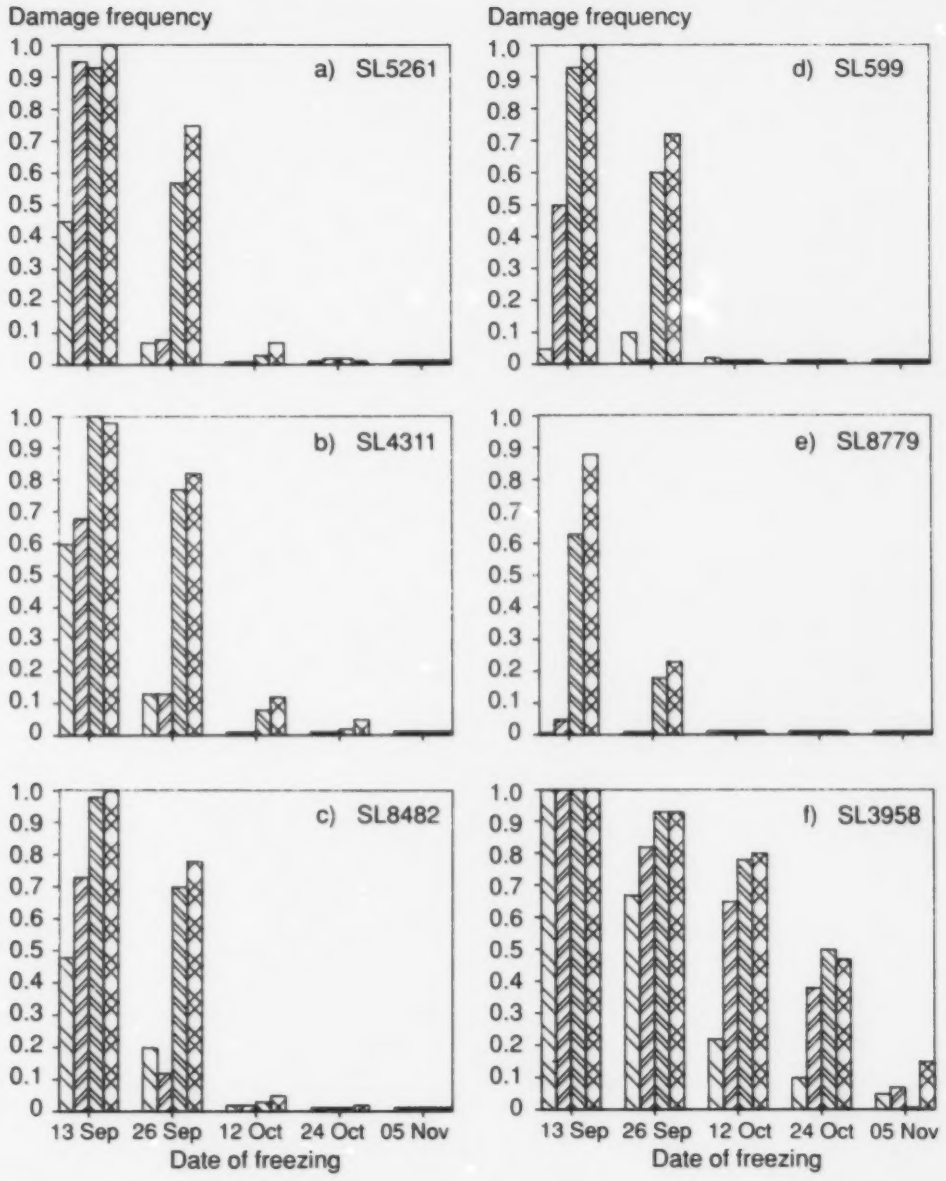

FIGURE 19. Foliage damage in response to a 1-h exposure at -18°C during the fall of 1988 at RRRS. Durations are pooled within a photoperiod bar. 13-h P bar-1; 15-h P bar-2; 17-h P bar-3; and 19-h P bar-4. a) SL5261, b) SL4311, c) SL8482, d) SL599, e) SL8779, and f) SL3958. Because of the small sample size and subjectiveness of the assessment, no significance testing has been done.

Exposure to short photoperiods during the summer nursery phase resulted in enhanced foliage frost hardiness during September (Figure 19) except for the Sitka spruce hybrid seedlot. If B.C. Forest Service recommendations for frost hardiness and seedling lifting had been followed, all seedlots except 3958 could have been lifted in early October. However, root mass was still accumulating at a significant rate at this time (Figure 5), so lifting was not contemplated. Seedlot 3958 had acquired sufficient foliar frost hardiness to be lifted by late October and it still displayed the effects of nursery photoperiod treatments (Figure 19).

Durations within a photoperiod were also pooled, as was done for foliage damage measurements, in the cambial and bud damage assessments. Early in the fall, those seedlings exposed to shortened photoperiods had a minimum degree of cambial injury (Figure 20). Seedlots 8779 and 599 had little or no cambial damage by September 26, presumably because they were the most northerly of the interior seedlots and were "hardening off" in response to the rapidly shortening days. Initially (before October 12), shorter photoperiod treatments enhanced cambial frost resistance in SL3958 seedlings (Figure 20). Before mid-October, short-day treatments were associated with a greater resistance to cambial damage than were the long-day and ambient treatments (Figure 20). After this date, short-day treatments led to reduced resistance while long-day treatments led to continued increases in cambial frost resistance for SL3958. At lifting, for all the seedlots, the cambial damage frequency was less than 0.2.

Short photoperiod treatment (13 h) gave some degree of frost protection to apical buds in early October for all seedlots (Figure 21). By the time of lift, some seedlots had increased in bud frost hardiness, while others remained relatively unchanged. One trend that emerged for all seedlots between the penultimate and last assessment was that stock exposed to the longest photoperiod (19 h) was *increasing* in bud frost hardiness while stock exposed to the shortest photoperiod (13 h) was *losing* bud frost resistance. These data indicate that seedlings treated with short photoperiods rapidly move through induction processes, and past the point of maximum bud frost resistance while still in the nursery.

This interpretation is consistent with that of Fuchigami and Nee (1987). It can be described as a nursery treatment-induced shift in the Degree Growth Stage Model. How important a consideration this is for storage or field performance is not clear, and an explanation at the cellular level is needed.

3.2.3 Days to bud break (DBB)

Analysis of days to bud break indicated that DBB was significantly affected by seedlot, photoperiod, and application duration at the time of lifting in 1988 (Table 15). Because SL3958 had not received sufficient chilling to flush in a 7-week test, it was excluded from the fall analysis. The ranges of DBB for photoperiod, duration, and seedlot were 7.5, 3.7 and 5.6 days, respectively. The critical range of significance in the fall was about 2 days between treatments and seedlots (Table 16). While this range is statistically significant, it is likely of little biological relevance. The effect of storage on DBB was to reduce the number of days required to flush (Table 16).

Analysis of variance (Table 17) on all 72 treatment combinations in the spring show that DBB was significantly influenced by seedlot, photoperiod, and duration of photoperiod application. The ranges of DBB were 2.2, 0.6 and 1.0 days, respectively, for photoperiod, duration and seedlot. The critical range of significance is about one-half day between treatments and seedlots. Once again this was of statistical, but probably not biological, significance.

The decrease in DBB over time and for decreasing photoperiod (durations pooled) is illustrated for seedlot 599 (Figure 22). This seedlot was also tested for DBB in late January, about mid-way through storage. The January values are much closer to the spring than to the fall values. Dormancy is assumed to be inversely related to the number of days to bud break (Campbell 1978; Ritchie *et al.* 1985). These data indicate that dormancy is lost quite quickly in storage. At the end of cold storage, the effect of photoperiod treatments on days to bud break was small. The range in DBB for SL599 was 1.3 days for photoperiod and duration.

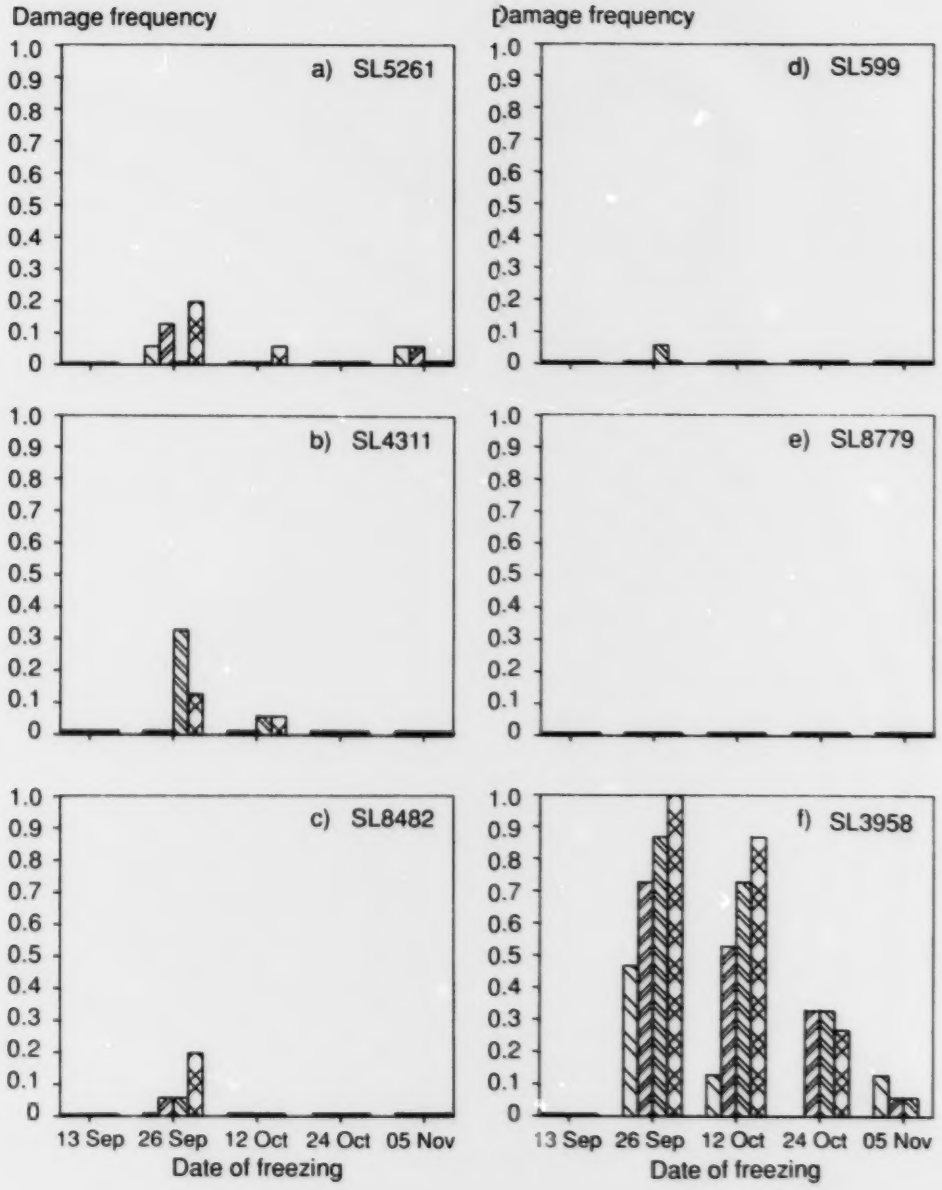

FIGURE 20. Cambium damage in response to a 1-h exposure at -18°C during the fall of 1988 at RRRS. Durations are pooled within a photoperiod bar. 13-h P bar-1; 15-h P bar-2; 17-h P bar-3; and 19-h P bar-4. a) SL5261, b) SL4311, c) SL8482, d) SL599, e) SL8779, and f) SL3958. Because of the small sample size and subjectiveness of the assessment, no significance testing has been done. The first data collection was on September 26, 1988.

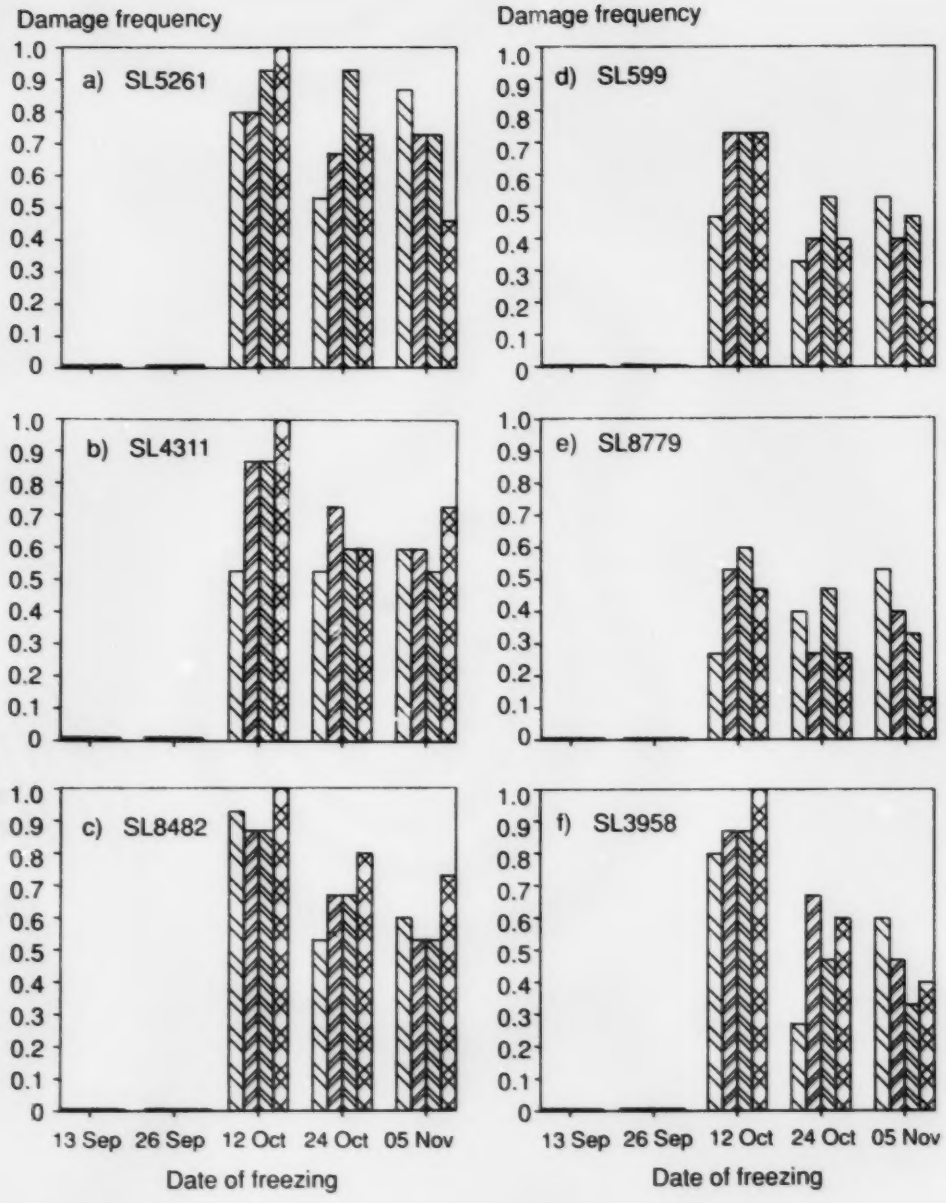

FIGURE 21. Apical bud damage in response to a 1-h exposure at -18°C during the fall of 1988 at RRRS. Durations are pooled within a photoperiod: photoperiod bar. 13-h P bar-1; 15-h P bar-2; 17-h P bar-3; and 19-h P bar-4. a) SL5261, b) SL4311, c) SL8482, d) SL599, e) SL8779, and f) SL3958. Because of the small sample size and subjectiveness of the assessment, no significance testing has been done. The first data collection was on October 12, 1988.

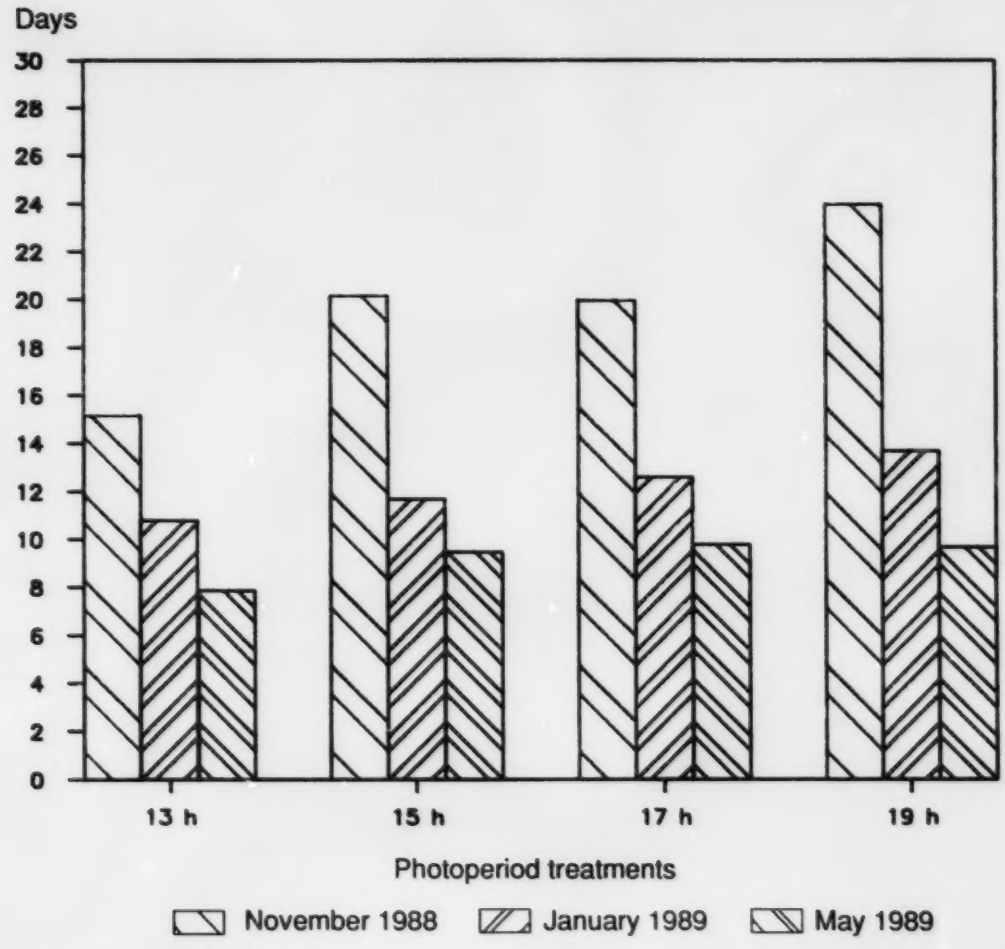

FIGURE 22. Days to bud break for SL599 at the time of lifting (November, bar-1) about halfway through freeze storage (late January, bar-2) and at planting (May, bar-3). Durations are pooled within a photoperiod.

TABLE 15. ANOVA of days to bud break at time of lift (November 2, 1988) by PxDxS treatment combination excluding the Sitka spruce hybrid seedlot. Probability of greater F value by chance, P>F.

Source	df	Mean square	F value	P>F
Photoperiod	3	755.1	11.52	0.0005
Duration	2	255.5	6.18	0.0236
Seedlot	4	143.2	5.52	0.0003
P x D	6	26.5	0.51	0.7936
P x S	12	60.3	2.32	0.0081
S x D	8	52.0	2.00	0.0063
Error	284	41.1		

TABLE 16. Days to bud break for all PxDxS combinations grown at RRRS in 1988 and tested at lifting (L) in the fall (November 1988) and at planting (P) in the spring (May 1989)

P	D	Time	Seedlot					
			5261	4311	8482	599	8779	3958[a]
13 h	2 wk	L	17.0	17.2	16.6	16.5	nt[b]	49
		P	10.1	8.9	8.9	8.7	9.1	9.2
13 h	4 wk	L	12.2	15.6	19.2	14.8	nt	49
		P	8.8	8.5	8.9	8.1	7.9	7.5
13 h	6 wk	L	12.8	13.0	13.6	14.4	12.0	49
		P	8.5	7.8	6.7	6.9	7.9	7.4
15 h	2 wk	L	17.8	17.8	17.2	28.7	16.8	49
		P	10.0	9.1	8.4	10.7	11.1	9.3
15 h	4 wk	L	15.2	15.4	16.6	16.4	15.8	49
		P	9.6	9.0	10.1	9.9	9.5	9.9
15 h	6 wk	L	15.2	14.8	13.6	15.4	14.8	49
		P	9.3	8.9	9.5	7.9	8.9	8.9
17 h	2 wk	L	26.8	23.0	22.2	19.4	17.6	49
		P	10.9	11.3	10.7	9.3	11.3	11.3
17 h	4 wk	L	18.0	20.8	16.6	22.8	16.4	49
		P	10.6	8.9	10.2	9.8	9.3	10.8
17 h	6 wk	L	19.4	20.2	20.4	18.0	14.4	49
		P	11.1	9.5	10.9	10.4	9.3	10.5
19 h	2 wk	L	32.2	19.3	18.0	25.8	19.0	49
		P	9.9	9.3	10.5	8.4	10.7	10.7
19 h	4 wk	L	32.8	20.4	21.8	27.0	16.8	49
		P	10.1	10.7	9.7	10.9	11.1	13.2
19 h	6 wk	L	18.8	22.6	25.0	19.2	18.4	49
		P	10.7	9.3	9.8	10.0	11.1	12.6

[a] Forty-nine or more days to bud break.
[b] nt – not tested.

TABLE 17. ANOVA of days to bud break at time of planting (May 13, 1989) by PxDxS treatment combinations. Probability of greater F value by chance, P F.

Source	df	Mean square	F value	P>F
Photoperiod	3	52.9	20.79	0.0001
Duration	2	6.5	5.85	0.0208
Seedlot	5	4.7	3.86	0.0026
P x D	6	6.0	4.93	0.5294
P x S	15	2.5	2.08	0.0140
S x D	10	1.1	0.91	0.5294
Error	143	1.2		

Overall, then, the short photoperiod treatments of the 1988 nursery season initially (November) promoted the loss of dormancy, but the final (May) range in DBB is not likely to be of practical significance (Figure 22). For all seedlots but SL3958, the range for DBB between the first and the last flushing treatment was 4 days or less, and it was just under 6 days for SL3958.

This runs contrary to the literature, where much larger treatment effects have been reported from blackout treatment and spring flushing (Hawkins and Hooge 1988; Odlum and Colombo 1988; Dormling 1989; Silim *et al.* 1989). This may be an indication of different phenology effects induced by static (Hawkins and Hooge 1988; Odlum and Colombo 1988) and dynamic blackout treatments, or of differences associated with storage. Spring phenological differences could possibly be further reduced if lifting were conducted according to common physiological status (foliage, bud, and cambium frost resistance, and DBB) rather than to a common date.

3.2.4 Root growth capacity (RGC)

Root growth capacity after storage in the spring of 1989 does not appear to be affected by the nursery treatments (Table 18). Arnott *et al.* (1988) reported a small but significant increase in RGC after a short-day treatment. The only possible exception is in seedlot 3958, the Sitka-white spruce hybrid, where spring RGC was greater in the longer photoperiod treatments than in the shorter ones. This is true whether modal frequency or mean RGC class is considered. Except for seedlot 3958 grown under 13-h photoperiod all durations and 15-h photoperiod 6-week duration, all root growth falls into the good to excellent category. Field root egress is not likely going to be a problem for seedlings from these 72 nursery treatments.

The high variability in RGC between treatments for seedlot 3958 (Table 18) may reflect its hybrid genetic background. This seedlot lagged behind others in attaining frost hardiness and meeting its chilling requirement, as indicated by DBB (Table 16). Seedlot 3958 may therefore not have been as "ready" to lift in early November as the others were. This variability at time of lift was also expressed when the seedlings were removed from storage.

3.2.5 Bud scale and leaf primordia estimates and counts

Estimates by PxD treatment are presented for SL8779 by time of lifting and storage, following over-winter storage, and by needle count after the 1989 field season (Table 19). Numbers of bud scales estimated in 1988 were significantly affected by P ($P>F=0.0001$, ANOVA not presented) and D ($P>F=0.03$), increasing significantly with increasing photoperiod and decreasing with increasing duration. Duncan's multiple range test (MRT) indicated that 13 h = 15 h < 17 h < 19 h, and 2 wk > 4 wk = 6 wk for numbers of bud scales (Table 20). Numbers of leaf primordia also increased with photoperiod and tended to decrease with duration. Duncan's MRT indicated that photoperiod extremes were significantly different in both estimated (1988) and counted (1989) needle numbers (Table 20).

Even though there were significant P and D differences in the numbers of leaf primordia estimated at season's end (1988), the rate of primordia production differed between treatments (S. Keates, Research Contractor, Red Rock Research Station, Prince George, B.C., pers. comm. Feb. 1989). Seedlings under 13-h photoperiod reached maximum primordia numbers before the end of August while control (19 h) seedlings did not achieve maximum numbers until season's end. The 15- and 17-h treatments reached their maximum in early-mid September. The effect of duration on leaf primordia initiation was not as marked as for photoperiod, but D1 stock reached maximum primordia numbers the latest in the season.

Needle counts on the preformed apical extensions after the 1989 growing season corroborated the significant P effect ($P>0.0001$, data not shown), although the main D effect was not significant.

These data indicate that the more severe the photoperiod and duration treatment, the earlier in the season primordia initiation ceased. However, these same treatments produced primordia at a much greater rate during the period of July through August. This suggests a photoperiod-induced alteration to carbon allocation (Zelawski 1957; Nelson 1963). The seasonal root mass accumulation data in this study support this assumption.

TABLE 18. Modal frequency class (MFC) and mean RGC class (MC) for all PxDxS combinations grown at RRRS in 1988 and tested in May 1989

		Seedlot											
		5261		4311		8482		599		8779		3958	
P	D	MFC	MC	MFC	MC	MFC	MC	MFC	MC	MFC	MC	MFC	MC
13 h	2 wk	4	3.7	3	3.4	4	3.3	3	3.1	4	3.4	2	2.7
13 h	4 wk	4	3.8	3	3.5	4	3.9	3	3.1	4	3.5	3	2.9
13 h	6 wk	4	3.9	4	3.9	4	3.9	4	3.7	4	3.7	3	2.9
15 h	2 wk	4	3.7	3	3.1	3	3.2	3	3.1	3	3.1	5	3.9
15 h	4 wk	3	3.2	3	2.9	3	3.5	4	3.7	3	2.9	4	3.5
15 h	6 wk	4	4.0	4	4.0	4	4.1	4	3.9	3	2.9	3	2.8
17 h	2 wk	3	3.3	3	2.9	4	3.7	4	3.6	4	2.6	5	3.7
17 h	4 wk	4	3.5	3	3.2	3	3.1	4	3.4	3	3.7	4	3.8
17 h	6 wk	4	4.1	4	3.4	4	3.8	4	3.8	4	3.9	5	4.2
19 h	2 wk	4	3.4	4	3.4	4	4.0	4	3.9	4	3.9	5	4.0
19 h	4 wk	4	4.1	4	3.5	4	3.3	4	3.7	4	4.0	5	4.5
19 h	6 wk	3	3.4	3	3.0	3	3.7	4	4.1	4	3.5	5	3.2

TABLE 19. Estimate of mean number and standard deviation (bracketed) of bud scales and leaf primordia at the end of the 1988 nursery season (n=5) and of leaf primordia following 6 months of cold-storage (n–15); and counts of needles on the 1989 preformed shoot (n=9) of SL8779. The variance between 1989 leaf primordia counts and primordia estimates is given in % deviation from needle count. Hours – h; weeks – wk; na – not available.

Treatment		End-of-season (1988) Bud scales		End-of-season (1988) Leaf primordia		After cold storage leaf primordia		End-of-season (1989) needles		May 1989 leaf primordia mean/Sept. 1989 needle
P	D	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	mean X 100
13 h	2 wk	40.4	(9.4)	260.4	(42.7)	292	(55.0)	262	(30.1)	+ 12
13 h	4 wk	31.8	(3.1)	261.4	(36.3)	234	(50.1)	271	(14.3)	– 14
13 h	6 wk	38.6	(4.3)	229.6	(16.0)	236	(45.8)	280	(44.1)	– 16
15 h	2 wk	39.6	(8.8)	317.8	(69.0)	346	(51.0)	326	(40.6)	+ 6
15 h	4 wk	42.6	(6.3)	313.6	(68.1)	292	(61.7)	330	(37.6)	– 12
15 h	6 wk	38.0	(4.4)	278.6	(22.4)	258	(55.8)	279	(28.5)	– 8
17 h	2 wk	53.4	(6.1)	343.9	(53.6)	362	(77.3)	422	(60.2)	– 14
17 h	4 wk	47.6	(10.9)	274.4	(18.8)	356	(72.0)	373	(34.1)	– 5
17 h	6 wk	na	na	318.5	(97.3)	387	(57.8)	408	(76.6)	– 5
19 h	2 wk	72.6	(16.1)	383.6	(49.3)	384	(64.6)	409	(45.7)	– 6
19 h	4 wk	50.6	(12.6)	356.6	(24.7)	408	(56.2)	377	(23.2)	+ 8
19 h	6 wk	52.0	(7.3)	319.2	(54.4)	387	(58.4)	406	(20.0)	– 5

TABLE 20. Significance of P and D on bud scales and leaf primordia estimates for seedlot 8779 at the end of the nursery season (26 October) and needle counts following the 1989 growing season. Means followed by the same letter within a treatment column are not significantly different. Hours – h; weeks – wk.

Treatment		October 1988		September 1989
		Bud scales	Leaf primordia	Needle count
			Photoperiod	
13 h	P1	36.9 a	235.5 a	271.0 a
15 h	P2	40.1 a	303.3 b	311.5 a
17 h	P3	50.5 b	312.0 b	401.1 b
19 h	P4	58.4 c	352.8 c	397.3 b
			Duration	
2 wk	D1	51.5 a	326.2 a	354.8
4 wk	D2	43.1 b	290.0 b	337.2
6 wk	D3	42.8 b	286.5 b	343.2

Root mass was significantly greater in P1 treatments in mid- to late August. The rate of increase slowed for seedlings grown under this treatment, and by season's end the difference in root mass between photoperiods was not significant (Table 13). These observations indicate that extreme short-day treatments may result in alterations in carbon allocation patterns associated with changes in net photosynthesis.

3.3 Field Seasonal Growth Data

3.3.1 Phenology

Phenology class data describes the phenological development of all six seedlots over the first field season at RRRS (Tables 21–26). The modal class values (n = 54) show a progression over time from resting spring terminal bud (out of cold storage May 8, first assessment May 13, 1989), through to the formation of a resting terminal bud in fall 1989. Data are presented for each seedlot and PxD nursery treatment. Bracketed values identify phenology classes where a significant proportion (>20%) of the 54-tree sample was reflushing.

The white and Engelmann spruce seedlots (Tables 21–25) flushed, developed, and set terminal buds following a generally similar seasonal pattern. Buds were swollen 5 days after planting on May 13, 1989 (Julian day [JD] 133), and began flushing after approximately 2.5 weeks. Terminal bud scale formation began 9 weeks after planting (mid-July), and a resting terminal bud developed in mid-August, or 14 weeks after planting (Tables 21–25).

Photoperiod treatment effects are relatively small but consistent in early phenological stages. Short-day photoperiods and, to a lesser degree, long duration treatments accelerated flushing (class 2), lateral bud formation (class 3), and the formation of terminal bud scales (class 4) in comparison to ambient treatments (Tables 21–25). Differences between phenology classes 1–3 in the spring averaged a few days. Measurement frequency during the late summer and fall was reduced, and estimates of phenology class and date of class change are thus less precise.

Control seedlings set a resting terminal bud in all white and Engelmann spruce seedlots between August 11 (JD 223) and August 22 (JD 235) at RRRS in 1989 (Tables 21–25). In three of these 5 seedlots, nursery short-day treatments had no consistent effect on date of budset (Tables 21, 23 and 25). However, seedlots 4311 and 599, under 15- and 13-h short-day treatments, had a significant amount of reflushing (>20%), and an associated delay in terminal budset (Tables 22 and 24). Final terminal budset was delayed a maximum of 14 days in the longest duration and shortest photoperiod combination (Tables 22 and 24).

TABLE 21. Seedlot 5261 seedling terminal bud modal phenology class during the first (1989) field growing season at RRRS. Phenology classes are: 0 – resting spring terminal bud; 1 – swelling terminal bud; 2 – flushing (elongation) terminal bud (shoot); 3 – lateral buds forming on current shoot; 4 – terminal bud scales forming; and 5 – resting terminal bud. A bracketed phenology class value indicates >20% terminal bud reflushing. Seedlings planted on Julian day (JD) 133 (May 13, 1989). Hour – h; week – wk.

		1989 field growing season																
		May					June				July				August			September
	JD	133	136	139	143	149	152	157	171	180	188	194	202	209	215	223	235	249	275
13 h	2 wk	0	1	1	1	1	2	2	3	3	4	4	4	4	4	4	5	5	5
13 h	4 wk	0	1	1	1	2	2	2	3	3	4	4	4	4	4	4	5	5	5
13 h	6 wk	0	1	1	1	2	2	2	3	3	3	4	4	4	4	4	5	5	5
15 h	2 wk	0	1	1	1	2	2	2	3	3	4	4	4	4	4	4	5	5	5
15 h	4 wk	0	1	1	1	2	2	2	2	3	4	4	4	4	4	4	5	5	5
15 h	6 wk	0	1	1	1	1	2	2	3	3	4	4	4	4	4	4	5	5	5
17 h	2 wk	0	1	1	1	1	2	2	3	3	4	4	4	4	4	4	5	5	5
17 h	4 wk	0	1	1	1	1	2	2	3	3	3	4	4	4	4	4	5	5	5
17 h	6 wk	0	1	1	1	1	2	2	3	3	3	4	4	4	4	4	5	5	5
19 h	2 wk	0	1	1	1	1	2	2	2	3	4	4	4	4	4	4	5	5	5
19 h	4 wk	0	1	1	1	1	2	2	3	3	4	4	4	4	4	4	5	5	5
19 h	6 wk	0	1	1	1	1	2	2	3	3	4	4	4	4	4	4	5	5	5

TABLE 22. Seedlot 4311 seedling terminal bud modal phenology class during the first (1989) field growing season at RRRS. Phenology classes are: 0 – resting spring terminal bud; 1 – swelling terminal bud; 2 – flushing (elongation) terminal bud (shoot); 3 – lateral buds forming on current shoot; 4 – terminal bud scales forming; and 5 – resting terminal bud. A bracketed phenology class value indicates >20% terminal bud reflushing. Seedlings planted on Julian day (JD) 133 (May 13, 1989). Hour – h; week – wk.

		1989 field growing season																
		May					June				July				August			September
	JD	133	136	139	143	149	152	157	171	180	188	194	202	209	215	223	235	249	275
13 h	2 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	(4)	(4)	4	5	5
13 h	4 wk	0	1	1	1	2	2	2	2	3	3	3	4	4	4	4	5	5	5
13 h	6 wk	0	1	1	1	2	2	2	2	3	3	3	4	4	(4)	(4)	(5)	4	5
15 h	2 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	(4)	(4)	4	5	5
15 h	4 wk	0	1	1	1	1	2	2	2	3	3	3	4	4	4	4	4	5	5
15 h	6 wk	0	1	1	1	1	2	2	3	3	3	3	4	4	4	(4)	5	5	5
17 h	2 wk	0	1	1	1	1	2	2	2	3	3	3	4	4	4	4	5	5	5
17 h	4 wk	0	1	1	1	1	2	2	2	3	3	3	4	4	4	4	4	5	5
17 h	6 wk	0	1	1	1	1	2	2	2	3	3	3	4	4	4	4	5	5	5
19 h	2 wk	0	1	1	1	1	2	2	2	3	3	3	4	4	4	4	5	5	5
19 h	4 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	5	5	5
19 h	6 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	5	5	5

TABLE 23. Seedlot 8482 seedling terminal bud modal phenology class during the first (1989) field growing season at RRRS. Phenology classes are: 0 – resting spring terminal bud; 1 – swelling terminal bud; 2 – flushing (elongation) terminal bud (shoot); 3 – lateral buds forming on current shoot; 4 – terminal bud scales forming; and 5 – resting terminal bud. A bracketed phenology class value indicates >20% terminal bud reflushing. Seedlings planted on Julian day (JD) 133 (May 13, 1989). Hour – h; week – wk.

		1989 field growing season																
		May					June				July				August			September
	JD	133	136	139	143	149	152	157	171	180	188	194	202	209	215	223	235	249	275
13 h	2 wk	0	1	1	1	1	2	2	3	3	3	3	4	4	4	4	5	5	5
13 h	4 wk	0	1	1	1	2	2	2	2	3	3	3	4	4	4	4	5	5	5
13 h	6 wk	0	1	1	1	2	2	2	2	3	3	4	4	4	4	4	5	5	5
15 h	2 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	5	5	5
15 h	4 wk	0	1	1	1	1	2	2	3	3	3	4	4	4	4	4	5	5	5
15 h	6 wk	0	1	1	1	1	2	2	2	3	3	3	4	4	(4)	(4)	5	5	5
17 h	2 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	5	5	5
17 h	4 wk	0	1	1	1	1	2	2	2	3	3	3	4	4	4	4	4	5	5
17 h	6 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	5	5	5
19 h	2 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	5	5	5
19 h	4 wk	0	1	1	1	1	2	2	2	3	4	4	4	4	4	4	5	5	5
19 h	6 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	5	5	5

TABLE 24. Seedlot 599 seedling terminal bud modal phenology class during the first (1989) field growing season at RRRS. Phenology classes are: 0 – resting spring terminal bud; 1 – swelling terminal bud; 2 – flushing (elongation) terminal bud (shoot); 3 – lateral buds forming on current shoot; 4 – terminal bud scales forming; and 5 – resting terminal bud. A bracketed phenology class value indicates >20% terminal bud reflushing. Seedlings planted on Julian day (JD) 133 (May 13, 1989). Hour – h; week – wk.

		1989 field growing season																
		May					June				July				August			September
	JD	133	136	139	143	149	152	157	171	180	188	194	202	209	215	223	235	249	275
13 h	2 wk	0	1	1	1	1	2	2	3	3	3	3	4	4	(4)	(4)	5	5	5
13 h	4 wk	0	1	1	1	2	2	2	2	3	3	4	4	4	4	4	5	5	5
13 h	6 wk	0	1	1	1	2	2	2	2	3	3	3	4	4	(4)	(4)	4	4	5
15 h	2 wk	0	1	1	1	1	2	2	3	3	3	3	4	4	4	4	5	5	5
15 h	4 wk	0	1	1	1	2	2	2	2	3	3	3	4	4	4	4	5	5	5
15 h	6 wk	0	1	1	1	1	2	2	2	3	3	3	4	4	4	4	4	5	5
17 h	2 wk	0	1	1	1	1	2	2	2	3	3	3	4	4	4	4	5	5	5
17 h	4 wk	0	1	1	1	1	2	2	3	3	3	3	4	4	4	4	5	5	5
17 h	6 wk	0	1	1	1	1	2	2	3	3	3	4	4	4	4	4	5	5	5
19 h	2 wk	0	1	1	1	1	2	2	3	3	3	4	4	4	4	4	5	5	5
19 h	4 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	4	5	5
19 h	6 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	5	5	5

TABLE 25. Seedlot 8779 seedling terminal bud modal phenology class during the first (1989) field growing season at RRRS. Phenology classes are: 0 – resting spring terminal bud; 1 – swelling terminal bud; 2 – flushing (elongation) terminal bud (shoot); 3 – lateral buds forming on current shoot; 4 – terminal bud scales forming, and 5 – resting terminal bud. A bracketed phenology class value indicates >20% terminal bud reflushing. Seedlings planted on Julian day (JD) 133 (May 13, 1989). Hour – h; week – wk.

		1989 field growing season																	
		May					June				July				August			September	
	JD	133	136	139	143	149	152	157	171	180	188	194	202	209	215	223	235	249	275
3 h	2 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	5	5	5
13 h	4 wk	0	1	1	1	2	2	2	2	3	3	4	4	4	4	4	5	5	5
13 h	6 wk	0	1	1	1	2	2	2	2	3	3	3	4	4	4	4	5	5	5
15 h	2 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	5	5	5
15 h	4 wk	0	1	1	1	2	2	2	2	3	3	4	4	4	4	4	5	5	5
15 h	6 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	5	5	5
17 h	2 wk	0	1	1	1	1	2	2	3	3	3	4	4	4	4	4	5	5	5
17 h	4 wk	0	1	1	1	1	2	2	3	3	3	4	4	4	4	4	5	5	5
17 h	6 wk	0	1	1	1	1	2	2	2	3	3	3	4	4	4	4	5	5	5
19 h	2 wk	0	1	1	1	1	2	2	3	3	3	4	4	4	4	4	5	5	5
19 h	4 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	5	5	5
19 h	6 wk	0	1	1	1	1	2	2	2	3	3	4	4	4	4	4	5	5	5

TABLE 26. Seedlot 3958 seedling terminal bud modal phenology class during the first (1989) field growing season at RRRS. Phenology classes are: 0 – resting spring terminal bud; 1 – swelling terminal bud; 2 – flushing (elongation) terminal bud (shoot); 3 – lateral buds forming on current shoot; 4 – terminal bud scales forming; and 5 – resting terminal bud. A bracketed phenology class value indicates >20% terminal bud reflushing. Seedlings planted on Julian day (JD) 133 (May 13, 1989). Hour – h; week – wk.

		1989 field growing season																	
		May					June				July				August			September	
	JD	133	136	139	143	149	152	157	171	180	188	194	202	209	215	223	235	249	275
13 h	2 wk	0	1	1	1	2	2	2	2	3	3	3	3	3	3	3	3	4	5
13 h	4 wk	0	1	1	1	2	2	2	2	3	3	3	3	3	3	3	3	4	4
13 h	6 wk	0	1	1	1	2	2	2	2	3	3	3	3	3	3	3	3	4	4
15 h	2 wk	0	1	1	1	1	2	2	2	2	3	3	3	3	3	3	4	4	5
15 h	4 wk	0	1	1	1	2	2	2	2	3	3	3	3	3	3	3	4	4	5
15 h	6 wk	0	1	1	1	1	2	2	2	3	3	3	3	3	3	3	3	4	4
17 h	2 wk	0	1	1	1	1	2	2	2	2	3	3	3	4	4	4	4	4	5
17 h	4 wk	0	1	1	1	2	2	2	2	2	3	3	3	3	3	3	4	4	5
17 h	6 wk	0	1	1	1	2	2	2	2	2	3	3	3	3	3	3	3	4	4
19 h	2 wk	0	1	1	1	1	2	2	2	2	3	3	3	4	4	4	4	5	5
19 h	4 wk	0	1	1	1	1	2	2	2	2	3	3	3	3	3	3	3	4	5
19 h	6 wk	0	1	1	1	1	2	2	2	2	3	3	3	3	3	4	4	4	5

The hybrid seedlot shoot elongated for a longer period of time than the other seedlots and did not form visible terminal bud scales until late August (Table 26). The resting terminal bud stage was difficult to determine in this seedlot, but probably occurred in mid-September for control treatments and in late September for short-day photoperiod treatments. These observations are similar to those of Hawkins and Hooge (1988) for a static, photoperiod-treated hybrid seedlot. The data presented are also consistent with the observations of Olson *et al.* (1959). That is, seedlings from high elevation or northern origins set bud earlier than those of low elevation or southern origin.

The difference between phenology stage 4 (terminal bud scales forming) and stage 5 (presence of a resting terminal bud) is particularly subjective, and the difference in resistance to cold stress of these phenological stages is not known. Therefore, the importance of a 1- or 2-week shift in end of season phenology class cannot be stated with any certainty in terms of practical field implications. However, Hawkins and Hooge (1988) did report greater early-winter terminal bud mortality in short, photoperiod-treated hybrid Sitka-white spruce stock in a separate study where static blackout treatments were used. It is possible that the minimal alterations to bud phenology observed after storage in this experiment are a function of the dynamic blackout treatment tested. A comparison of the effect of dynamic and static blackout treatments on bud phenology must yet be done. Differences between control and extreme short-day treated stock could possibly be further minimized if lifting were based on seedlings achieving common physiological status rather than passing a certain point of development or time.

3.4 End of 1989 Field Growing Season

3.4.1 Field morphology

Analysis of first field season height and ground-line stem diameter increment at RRRS is summarized in Table 27. Exclusion of the Sitka-white spruce hybrid seedlot caused three of the seven model terms to change significance for the variable height increment, but had no effect on the status of diameter or volume increment terms.

With the hybrid seedlot deleted, first field season height increment was not significantly affected by D main effects or by the PxD or PxDxS interactions (Table 27). Seedlot effects were highly significant ($P>0.0001$), but the first-order interaction of SxD and PxS was not. Seedlots ranged from 107 to 146 mm in height increment, with the relatively poor nursery performer (5261) and the Interior Tree Improvement Program seedlot (599) being the lowest and highest, respectively.

Total range in height increment between levels of photoperiod tested was only 12 mm, and between levels of D was less than 5 mm, in the white and Engelmann spruce seedlots.

The hybrid Sitka-white spruce seedlot, measured on September 24, 1989, averaged 126 mm in height increment. Height increment was inversely related to severity of short-day treatment: the 13-h treatment averaged 149 mm; the 15-h, 146 mm; 17-h, 116 mm; and the 19 h (or ambient), 91 mm. This is consistent with first field season results obtained for this seedlot previously (Hawkins and Hooge, unpublished data). The overall responsiveness of the Sitka hybrid to photoperiod treatment in the nursery appears to carry over in the field, while the generally less responsive white and Engelmann spruce seedlots have little or no short-day carry-over effect in their first-year field height increment. It should be noted that the RRRS field site is well out of the natural range of the hybrid seedlot.

Ground-line stem diameter increment analysis indicated no change in model term significance status without the Sitka hybrid deleted from the data set (Table 27). Photoperiod, duration, and seedlot main effects on diameter were all highly significant ($P>0.001$), as were PxD and PxS interactions ($P>0.05$) (Table 27). The PxD interaction is attributable to the experimental artifact of D being non-significant within the control photoperiod. Diameter increment was greatest with short-day treatment (P1, 13 h) and least under ambient photoperiod (P4, 19 h). Although the actual increment range was only 3.3–3.9 mm, the differences were highly significant statistically.

The significant photoperiod and seedlot interaction is attributed to an apparent inconsistency in seedlot 5261. While the other five seedlots consistently increase in diameter increment with decreasing day length, the 19-h (control) diameter increment in SL5261 is relatively large. No explanation is offered

TABLE 27. Summary of seedling mean height, diameter and volume increment analyses at the end of the first farm-field season (September 24, 1989). Abbreviations: NS, non-significant (P<0.95); S, significant (P≥0.95). Brackets indicate a change in significance with the exclusion of the Sitka spruce hybrid seedlot (3958).

Source	Height Increment	Diameter Increment	Volume Increment
Photoperiod	(NS)	S	S
Duration	NS	S	NS
Seedlot	S	S	S
P x D	NS	S	S
P x S	(S)	S	NS
S x D	(S)	NS	NS
PxDxS	NS	NS	NS

for this. Over all seedlots, the first field season diameter increment of the 13-h treatment averaged 19% higher than that of the control (19-h) treatment.

Seedling volume increment analysis in the first field season was not sensitive to the exclusion of the hybrid seedlot and showed significant seedlot and photoperiod main effects (Table 27). The hybrid and tree improvement program seedlot had the greatest volume increment (3791 and 3741 mm^3, respectively) and seedlot 5261 the least (2490 mm^3). Intermediate photoperiod treatments resulted in the greatest volume increment in the first field season, despite the initial size difference out of the nursery.

3.5 Overview of Nursery and First Field Season Assessments

Data from many of the areas discussed are summarized in Table 28 by P and D treatment. The view taken is that nursery performance is likely to be only a small part of a successful regeneration equation. Data are presented for the Sitka-white spruce hybrid (Sxs) and for the pooled white-Engelmann spruce seedlots (Sw-Se). The Sw-Se seedlots were pooled because of the generally small differences observed between them. Nursery short-day treatments of choice are suggested for Sxs and Sw-Se based on the 1988 experimental results.

In terms of nursery morphology, the best treatment for Sxs was 15-h photoperiod applied for 4 weeks. It gave good height control without severely affecting RCD (Table 28). This treatment also resulted in the greatest Sxs root mass. It was a compromise treatment, intermediate in photoperiod and duration, which achieved the desired shoot morphological goals without curtailing carbon translocation to the roots or reducing net photosynthesis.

The best nursery treatment appears to be 13-h photoperiod applied for a 2-week duration for the composite Sw-Se seedlot (Table 28). This treatment gave good height control without affecting RCD or root mass. Apparently, the less vigorous Sw-Se seedlots only require a brief application of short days to initiate and maintain the bud induction processes associated with height control in the 1988 growing season. In the more vigorous Sxs seedlot, this PxD treatment resulted in height control, but at the expense of root mass and some lateral lammas growth.

By the time of lift, frost resistance (-18°C test) was adequate for both the Sxs and the composite seedlot (Table 28). Fall DBB was not affected by PxD treatment in Sxs, but the treatment of choice (13-h P, 2-week duration) for the Sw-Se composite was in the mid-range of means (Table 28). There was a consistent relationship between PxD and chilling requirements for short-day treatments as indicated by the range of fall DBB for the composite seedlot: DBB decreased with increased duration and photoperiod.

TABLE 28. Nursery (fall) mean height (HT), root collar diameter (RCD), root dry mass (RDW), shoot dry mass (SDW), percentage foliage browning (FB), cambium damage (Camb.) and days to bud break (DDB) for Sxs and a white-Engelmann (5 seedlots pooled) composite seedlot by PxD treatment. Spring (planting) mean DBB and root growth capacity (RGC) and end of first farm-field season HT and RCD increments (Inc) are also presented. Hours – h; weeks – wk.

Treatment	HT (mm)	RCD (mm)	RDW (g)	SDW (g)	FB (%)	Camb. (%)	Fall DBB[a] days	Spring DBB days	RGC class	HT Inc (mm)	RCD Inc (mm)
						Sxs					
13 h 2 wk	195	3.2	0.63	1.65	15	40	49	9.2	2.7	138	2.5
13 h 4 wk	186	3.2	0.66	1.41	0	0	49	7.5	2.9	166	3.5
13 h 6 wk	182	2.6	0.60	1.41	0	0	49	7.4	2.9	144	3.9
15 h 2 wk	268	3.6	0.71	2.40	10	20	49	9.3	3.9	129	3.2
15 h 4 wk	191	3.3	0.74	1.83	10	0	49	9.9	3.5	157	3.1
15 h 6 wk	212	2.9	0.54	1.58	0	0	49	9.9	2.8	153	4.0
17 h 2 wk	296	3.1	0.57	2.24	0	0	49	11.3	3.7	97	3.4
17 h 4 wk	281	3.1	0.49	2.08	0	20	49	10.8	3.8	115	3.6
17 h 6 wk	280	2.8	0.54	1.98	0	0	49	10.5	4.2	135	3.1
19 h 2 wk	301	3.2	0.54	2.33	20	0	49	10.7	4.0	81	2.7
19 h 4 wk	314	3.4	0.60	2.58	20	0	49	13.2	4.5	95	3.3
19 h 6 wk	313	3.2	0.54	2.23	5	0	49	12.6	3.2	98	2.6
						Sw-Se					
13 h 2 wk	134	3.0	0.60	1.38	0	0	16.8	9.1	3.4	127	3.6
13 h 4 wk	134	2.3	0.52	1.21	0	0	15.4	8.4	3.6	120	4.2
13 h 6 wk	135	2.2	0.48	1.22	0	4	13.2	7.6	3.8	115	4.3
15 h 2 wk	144	3.0	0.54	1.43	0	0	19.7	9.9	3.2	136	3.6
15 h 4 wk	145	2.7	0.52	1.34	0	4	15.9	9.6	3.2	128	4.0
15 h 6 wk	140	2.5	0.55	1.36	0	0	14.8	8.9	3.8	134	4.3
17 h 2 wk	163	3.1	0.54	1.57	0	0	21.8	10.7	3.3	128	3.2
17 h 4 wk	164	3.0	0.53	1.54	0	0	18.9	9.8	3.4	135	3.4
17 h 6 wk	167	2.8	0.50	1.53	0	0	18.5	10.2	3.8	136	3.9
19 h 2 wk	182	3.0	0.55	1.71	0	0	22.9	9.8	3.7	135	3.5
19 h 4 wk	181	3.0	0.50	1.62	0	0	23.8	10.5	3.7	132	3.5
19 h 6 wk	186	3.0	0.50	1.71	0	0	20.8	10.2	3.5	123	3.2

[a] Forty-nine or more days to bud break.

The Sxs and Sw-Se treatments of choice resulted in a mid-range value for both DBB and RGC at the time of planting (Table 28). These data suggest that selecting PxD treatment combinations according to minimal morphological reductions or perturbations has a moderating effect on physiological parameters investigated up to the time of planting.

Farm-field growth results after one season must be regarded as interim results. However, for Sxs, the 15-h P and 4-week duration treatment had the second greatest height increment (range of 85 mm) and was intermediate in terms of RCD (range 1.5 mm) increment (Table 28). The treatment of choice did not inhibit field height or RCD growth. Height (range 21 mm) and RCD (range 1.1 mm) increments were mid-range for the composite seedlot (Table 28). The differences in field increments between treatments were small for the Sw-Se composite seedlot, as they had been in the nursery portion of the trial. This perhaps reflects the relatively low vigour of these seedlots when grown at RRRS.

The long-term effect of nursery photoperiod treatments cannot be properly analyzed until after the second, third or possibly even fifth growing season. It appears at this stage that the more responsive a seedlot is to photoperiod treatment in the nursery, the more variable the field response.

4 SUMMARY AND CONCLUSIONS

The nursery data presented in this report are the result of the phenotypic expression of the various seedlots influenced by cultural treatments, the general macroclimate for the year, and geographic locale. Results obtained in 1988 may have been altered if treatments had been initiated at earlier or later dates, or in a different nursery. Based on the data, there are two seedlot groupings, the vigorous Sitka-white spruce hybrids and the less vigorous white and Engelmann spruce seedlots.

Seedlot vigour is one variable that may be translocated from nursery to nursery. Vigorous seedlots display major blackout treatment effects, while low vigour seedlots respond minimally to photoperiod treatment. There also appear to be different "best" photoperiod treatments for the seedlot groupings by vigour. The hybrid required an intermediate photoperiod for an intermediate duration, while the others required a short photoperiod for a short duration. This argues against use of the conventional 10-h day:14-h night treatment to optimize seedling growth and performance. In fact, these data indicate that different blackout strategies are required to optimize the response of different spruce species with different levels of physiological vigour.

The effect of photoperiod manipulation on seedlots is a complex phenomenon. Conditions provided during seedling development may influence its later degree of bud dormancy (Dormling 1989). There are immediate responses to photoperiod, such as increased carbon allocation to the roots and leaf primordia development in the more extreme photoperiod treatments. Short days and increased application durations enhanced the acquisition of frost hardiness, an intermediate-term response. A more complex intermediate-term response is the rapid DBB of short-day, long-duration treatment seedlings. This indicates an interaction between photoperiod and chilling requirements, which accelerates movement through the Degree Growth Stage Model described by Fuchigami and Nee (1987). Long-term photoperiod effects were small, but significant differences existed between treatments for spring DBB and seasonal bud phenology. There is a possibility that long-term photoperiod effects could be minimized if the various treatment combinations were lifted at a common physiological stage rather than at a common date.

The alterations observed in spring DBB and seasonal bud phenology were much less in the Sitka-white spruce hybrid than previously described for this species at this locale (Hawkins and Hooge 1988). Their seedlings were grown under a static blackout treatment while this stock was grown under a dynamic blackout treatment and this could account for the difference. These divergent results from different nursery seasons indicate the need for a direct comparison of static and dynamic blackout treatments in the same cultural season.

The amount of growth after the initiation of blackout treatment was related to the size of the seedling at the time of treatment: large seedlings grew more than did small ones. This suggests that the possibility of minimizing seasonal macroclimate and cultural differences should be studied. With regression analyses, probability-based predictive models could be constructed for the most vigorous seedlots, so that blackout application date could be determined if the current mean seedling height and the final mean target height were known.

Overall, these data indicate that short-day dynamic photoperiod treatments, of longer than conventional blackout day length used in British Columbia, did control seedling height without causing major dry matter losses to the roots. They also resulted in stock which had minimal phenological disruption in the subsequent season, no carry-over on farm-field height increment, and a positive effect on farm-field root collar diameter growth.

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